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GLACIAL AND INTERGLACIAL BEDS NEAR TORONTO

An article on the present subject was published in 1895 in the JOURNAL OF GEOLOGY;[1] but the five years since that time have added so much to the completeness of our knowledge of this important Pleistocene area as to justify a fresh account of the region. At the Toronto meeting of the British Association in 1897 the series of interglacial beds for which Professor Chamberlin had suggested the name "Toronto Formation" aroused so much interest that a committee was appointed for its investigation and grants were made at this and the two following meetings to cover the expense of excavations to solve some problems in connection with the beds. The final report of the committee, prepared by its secretary, the present writer, with a separate report on Pleistocene plants in Canada by Professor Penhallow, was made at Bradford in 1900, summing up the facts and giving lists of the interglacial fauna and flora, thus providing the materials for a more complete discussion of the events recorded in the "drift" of the region than has been attempted before.

The interglacial beds of Scarboro' near Toronto were first studied more than 20 years ago by the well-known English pale-

[1] JOUR. GEOL., Vol. III, No. 6, pp. 622, 645.

ontologist, Dr. George Jennings Hinde,[1] but his excellent work attracted little attention and the importance of the facts brought to light seems to have been overlooked by Pleistocene geologists. In 1894 the Don interglacial beds were described by the present writer,[2] who has since then given careful study to the numerous

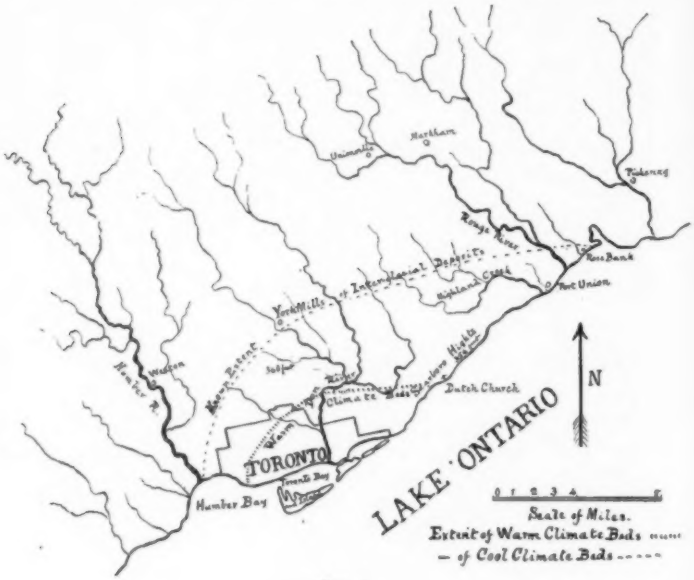


FIG. 1.

and excellent sections presented by Scarboro' Heights, the ravines of the Don, and many excavations carried on in and about the city of Toronto. A large number of fossils have been collected by Mr. J. Townsend and the writer, and Professor Penhallow has determined the plant remains, Dr. Dall and his assistants the shells, and Dr. Scudder the insects. These gentlemen have shown the greatest skill and patience in working up what was often very difficult material, and much of the value of the results of the investigation is due to them, particularly in determining

[1] Canadian Journal, 1878, p. 388 *et seq.* [2] Am. Geol., Vol. XIII, 1894, pp. 85–95.

the important changes of climate indicated. In the following paper an attempt will be made to give a connected history of the events which have occurred in the Ontario basin during the time represented by the Toronto Formation and the sheets of till below and above it, generally held to belong respectively to the Iowan and Wisconsin ice advances.

RETREAT OF THE IOWAN ICE SHEET

The retreat of the Iowan ice was probably accompanied by one or more lakes similar to those whose raised beaches, formed during the retreat of the last ice sheet, are so well marked around the present great lakes. Though no remnants of Iowan beaches are known to exist, there is strong faunal evidence of at least one glacially dammed Iowan lake. When the region was ice covered, all aquatic life must have been destroyed, so that any species occurring in interglacial beds must have migrated into the region from river systems beyond the reach of the ice. The unios which are so striking a feature of the lower beds of the Toronto Formation are Mississippi forms. As there is no more proof of direct connection between the Ontario basin and tributaries of the Mississippi during interglacial times than now, we may suppose that these shellfish entered the basin in a round-about way by means of an interglacial upper lake, draining at first past Chicago into the Mississippi, but afterwards finding an outlet by the Laurentian river into the Ontario valley and thence into the gulf of St. Lawrence.

After the Iowan glacier had retreated so far that lakes dammed by it had been drained, the St. Lawrence system of waters no doubt returned to much the same channels as before the advance of the ice, since there is no evidence that any great thickness of drift had been left to block the way. The lowest till at Toronto is generally thin, running from a foot or more near the bend of the Don at the paper mill to 8 or 9 feet at the Gerrard street bridge. At one point in the west end of the city, however, 35 to 40 feet of till occur, but a well-defined "bowlder pavement," with all the stones at the same level and striated on

their upper surfaces, is found 4 or 5 feet above Lake Ontario, and perhaps indicates that the upper 30 feet are of later age than the Iowan. Farther west along the shore of the lake the till sheet is not more than 10 or 15 feet thick. So far as known, this layer of till is nowhere thick enough to have modified greatly the shape of the surface, which may now be roughly sketched.

The highest point of the Hudson River shale near Toronto is at Weston, 7 miles northwest of the city, where it reaches about 200 feet above Lake Ontario. In the Don valley the shale runs from a little below lake level near the mouth of the river to 30 feet above it 2 or 3 miles to the north; but 5 miles east of the Don a well sunk at the foot of Scarboro' Heights failed to reach the rock at 41 feet below the lake, and beyond this bedrock is not found for a long distance, first appearing at Pickering, 15 miles to the east. This implies a width of about 25 miles for the mouth of the valley occupied by the preglacial (and also interglacial) Laurentian river whose old channel from Georgian Bay to Scarboro' has been indicated by Dr. Spencer.[1] The valley narrowed somewhat rapidly, however, toward the northwest, for on the upper reaches of the River Rouge between Unionville and Markham numerous angular slabs of Hudson River rock, evidently not far from their source, are found more than 300 feet above Ontario. The distance from this point to Weston is 16 miles in a southwesterly direction, and between the two points, the ravines of the Don and wells which have been sunk prove that a channel of considerable depth existed.

[1] Duration of Niagara Falls and History of the Great Lakes, pp. 18 and 19.

Dr. Spencer's idea of a present channel 474 feet deep, running from Scarboro' Heights across Ontario to the deep water near the south shore seems founded on an erroneous sounding as marked on Bayfield's chart. A series of soundings carried out by the present writer in 1898 across the supposed deep channel showed no such interruption in the gentle southward slope of the bottom, the depth at about the position of the 474 feet sounding on the chart being 175 feet. Probably the 4 is in mistake for 1, and the true sounding was 174 feet. The old channel across Lake Ontario was filled in completely, so far as one can ascertain, by stratified clay and till in later times and so has long ago disappeared. The fact that Scarboro' Heights, rising 375 feet above the lake, have been piled up since then may be considered sufficient proof of this.

We may suppose then that the great preglacial valley, though coated with a sheet of bowlder clay by the Iowan ice, had probably much the same form and dimensions at the end of that ice invasion as before. If there was an interglacial episode similar to the postglacial lake Iroquois no certain remains of its beach deposits are known, and the level of the water when the laying down of the Toronto Formation began was not greater than that of Lake Ontario and may have been considerably beneath it; for the lowest unio beds lie more than 40 feet beneath the present lake at Scarboro'.

Before the formation of similar beds at higher levels considerable erosion took place, as at the bend of the Don where these deposits occupy an old river channel cut through the Iowan till into the Hudson River shale to the depth of at least 16 feet, as shown by a cutting of the Don, at this point 19 feet above Ontario. The bowlder clay has been cut through to the shale in the western part of Toronto also, as shown in a well bored for purposes of exploration, the bottom of the interglacial deposits being 17 feet above Lake Ontario. It seems clear that rivers had been at work for some time before the unio beds were formed.

WARM CLIMATE BEDS OF THE DON VALLEY

The earliest beds of the Toronto Formation were deposited on the eroded surface of the Iowan till or on the shales which had been laid bare beneath it by river action; and they were formed probably in the shallow waters of a lake, though some features suggest the action of currents. At the bend of the Don, coarse, little rounded shingle of the harder layers of the underlying Hudson River rocks makes the lowest bed visible above the present river, and suggests the action of a current rather than of waves. Thick sheets of vegetable matter, greatly decayed twigs, leaves, reeds, etc., with trunks and branches of trees are interbedded with the shingle, however, showing that the current could not have been swift. Possibly these beds were formed just at the mouth of a small river like the present Don, where it entered a lake standing 20 or 30

feet higher than Ontario. If this is correct there had already been a damming back of the interglacial waters to a higher level than has been reached yet in postglacial times. This damming could not have been by ice, for the climate was at least as mild as at present, since the tree trunks referred to include wood of the red cedar, an elm, the pawpaw and three species of oak; and among the shellfish there are two not reported from Canadian waters at the present day, though found in the Mississippi, Quadrula (unio) pyramidata and Anodonta grandis.[1]

As the beds at Taylor's brickyard, which have been described in former papers, have been traced as far east as the bend of the Don at the edge of the interglacial valley just referred to and also as a thin lower layer across these deposits, we may include the whole in one section, commencing with the bend of the Don as a basal series and running up through the series at the brickyard as far as the cold climate stratified clays.

SECTION AT TAYLOR'S BRICKYARD

		Feet
8.	Yellow or brown sand with some reddish clay (no fossils)	3–60½
7.	Blue peaty clay with some gray sand (unios, wood, caribou horn)	4½–57½
6.	Yellow to brown sand with thin layers of purplish clay (shells)	14–53
5.	Fine gray and yellow sand (unios and other shells)	3–39
4.	Blue stratified clay and sand (unios with other shells and logs of wood), above 2½ feet of bowlder clay resting on Hudson River shale	2–36

SECTION AT BEND OF DON

3.	Brown clay with sandy layers (unios, campeloma, etc.)	5–34
2.	Blue clay with sandy layers (unios, anodons, wood)	6–29
1.	Coarse shingle with clay and peaty layers (shells and logs)	4–23
	River Don above Lake Ontario	19–19

From the combined section given above it will be seen that the warm climate beds of the Don commencing 19 feet above Lake Ontario have a total thickness of 41½ feet. It should be

[1] Notes on Can. Unionidae, J. F. WHITEAVES, Can. Rec. Science, 1895, No. 5, p. 250; and No. 6, p. 365.

added however that no fossils have been obtained from the uppermost three feet of brown sand. The lower section differs slightly in fauna from the upper one, containing numerous anodons and campelomas, which are almost absent from the beds at the brickyard; but the unios and trees are alike.

In previous papers the warm climate beds have been represented as ending just beneath the peaty blue clay (No. 7) which was considered to belong to the cool climate beds, chiefly because it contained peaty layers and had yielded a shed horn of caribou. Recently, however, the peat has been examined and found to contain no mica scales and very few mosses or spruce needles, which are very characteristic of the peaty layers belonging to clays of the cool climate. Instead of this the brown layers consist mainly of fragments of deciduous leaves. The recent finding of unios at the top of the blue clay strengthens the opinion that it and the brown sand above should be included with the warm climate beds. The lowest point at which the unio clays and sands have been found is 41 feet below Lake Ontario at the foot of Scarboro' Heights, giving a vertical range of more than 100 feet for the whole series of warm climate beds The following species have been obtained in the Don beds:

FAUNA OF WARM CLIMATE BEDS, DON VALLEY

Vertebrata: possibly mammoth or mastodon and bison, and an undetermined fish.

Arthropoda: several undetermined beetles and cyprids.

Mollusca:

Unio undulatus " rectus " luteolus " gibbosus	still living in Lake Ontario.
" phaseolus " pustulosus " trigonus " coccineus	still living in Lake Erie, but not reported from Lake Ontario.
" occidens " solidus " clavus " pyramidata	not known in the St. Lawrence system of waters, but living farther south.

Anodonta grandis, not reported from Canada.
Sphaerium rhomboideum
" striatinum
" sulcatum
" solidulum
" similis (?)
Pisidium Adamsi
" compressum
" novaboracense (?)
Pleurocera subulare
" elevatum
" Lewisi (?)
Goniobasis depygis
" Haldemani
Limnaea decidiosa
" elodes
Planorbis parvus
" bicarinatus
Amnicola limosa
" porata
" sagana
Physa heterostropha
" ancillaria
Succinea avara
Bythinella obtusa
Somatogyrus isogonus
Valvata sincera
" tricarinata
Campeloma decisa
Bifidaria armata (land snail)

In all there are thirty-nine undoubted species of mollusks, and three more probably, included in the fauna. Of these eight or ten have not been reported from Lake Ontario, but occur farther south.

FLORA OF WARM CLIMATE BEDS, DON VALLEY

Acer pleistocenicum
" spicatum
Asimina triloba
Carya alba
Chamaecyparis sphaeroidea
Crataegus punctata
Cyperaceae sp.
Eriocaulon sp.
Fraxinus quadrangulata
" sambucifolia
" americana
Festuca ovina
Hypnum sp.
Juniperus virginiana
Larix americana
Maclura aurantiaca
Picea nigra
" sp.
Pinus strobus
Platanus occidentalis
Populus balsamifera
" grandidentata
Prunus sp.
Quercus obtusiloba
" alba (?)
" rubra
" tinctoria
" oblongifolia
" macrocarpa
" acuminata
Robinia pseudacacia
Salix sp.
Taxus canadensis
Thuya occidentalis
Tilia americana
Ulmus americana
" racemosa
Vaccinium uliginosum

Professor Penhallow, from whose report to the British Association in 1900 this list is taken, states that "within this area no less than thirty-eight species have been recovered, and they point conclusively to the existence of climatic conditions differing materially from those which now prevail, and of a character more nearly allied to those of the middle United States of today." "Only one species appears to have disappeared in Pleistocene time. Acer pleistocenicum, which was abundant in the region of the Don, bears no well defined resemblance to existing species."

The plant remains consist chiefly of wood and leaves, the former usually much flattened from the pressure of the later ice sheet, but otherwise often well preserved, the red cedar, for instance, showing its color and being still quite tough, although some of the wood, probably decayed before being waterlogged and included in the clay, is in a worse condition. Parts of the wood are almost of the nature of brown coal breaking across easily and showing a coaly luster on the broken surfaces. It may be worthy of mention that some large bits of porous charcoal, as if from the burning of a log, were found cemented with limonite in the sand (No. 6) just under the blue clay. The leaves are preserved generally in the thinner beds of clay and are rarely obtained whole.

The sands of the Don beds vary greatly in fineness and color, and are more or less cross bedded and mixed with gravel, as if deposited under wave action; while the coarse shingle at the base of the section near the bend of the Don looks like the work of a river. The upper part of the warm climate beds of the Don, consisting of stratified clay (No. 7) and sand (No. 8) appears to have been formed under distinctly lacustrine conditions. At the beginning of the formation there may have been no lake, only a great river with a tributary or tributaries coming in from the west; but at its close there was a great lake which stood at least sixty feet above Lake Ontario at present. Whether the change in water levels was slow or rapid there is no evidence to show. That the water remained for some time

at the higher level is testified by the thorough oxidation of the iron in the upper sandy beds, which are in some layers deep brown in color, and completely cemented with limonite. The blue layers (2, 4 and 7) have retained their color because of the large amount of deoxidizing vegetable material present in them.

The change in the level of the interglacial lake effected a great change in another respect. Where the valley of the Laurentian river had existed there was now a broad and deep bay running to the north, and the great river began to spread out clay and silt derived from its upper reaches in this basin. The upper bed of blue clay may have been formed by a shifting of the current of the main river, which, however, shifted again while the highest layer of sand was formed, bringing to a close the beds belonging to the warm climate series.

The extent of the Don beds, as indicated by the typical unio sands and clays, is not known very thoroughly, owing to the depth at which they are buried in most places. They occur a few feet below Lake Ontario at Scarboro', four miles southwest of Taylor's brickyard and at Price's brickyard about half way between; and unios have been found in sandy beds of interglacial age at Adare's sand pit on Shaw street, about three miles west of Taylor's. As logs of wood have been found by well diggers at points between, there is a strong probability that the Don beds continue to that point, in which case they have a known extent from east to west of more than six miles, with a breadth from north to south of more than two miles. The real area is probably much greater than this.

THE SCARBORO' OR COOL CLIMATE BEDS

After the close of the Don period the interglacial lake deepened greatly, finally standing more than 150 feet above Lake Ontario, and a great series of clays and sands were deposited by the Laurentian river in the form of delta materials in the wide and deep bay, at this time extending still farther to the north than before. As seen at Taylor's brickyard, the clay beds, gray and finely

laminated, with a few thin peaty layers, rest conformably on the brown sand at the top of the Don beds. The thickness, however, is not great, on account of later interglacial erosion, at the

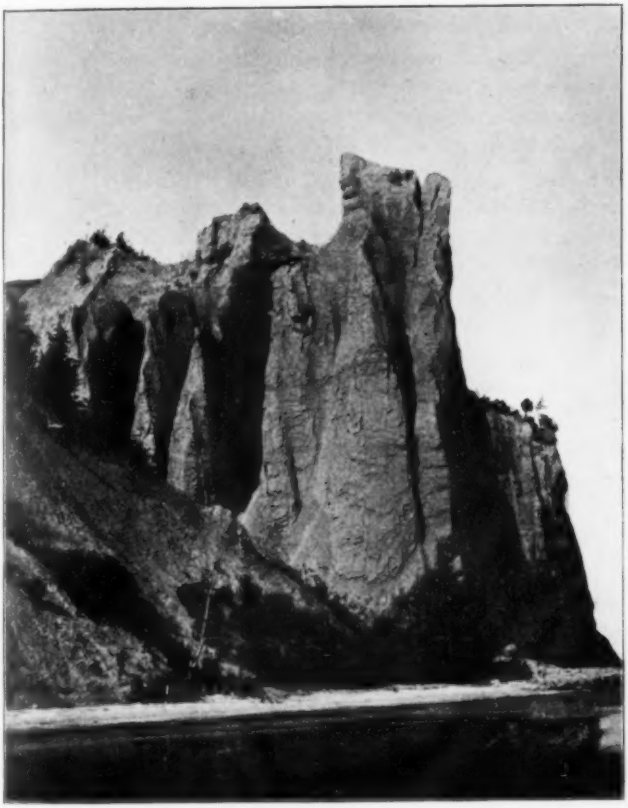


FIG. 2.—Pleistocene Cliffs of Scarboro' Heights.

south end of the clay pit only 7½ feet, 70 yards north, 13 feet, and a quarter of a mile to the northeast 30 feet. These clays are magnificently shown at Scarboro' heights, where they were carefully studied by Dr. Hinde. They commence, as shown in a

well sunk on the shore beneath the cliff, about five feet below Lake Ontario and rise 85 or 90 feet above it.[1] The upper surface mingles somewhat with the overlying sand and varies in height to some extent. The clay is gray, very firm and resistant, almost as much so as the Hudson River shale of the region, and is generally finely laminated, though there are beds from two to four or five feet thick, showing little or no lamination. Besides the fine lamination there are often thin layers of grayish silt with peaty material at distances of one or two inches apart, perhaps representing flood seasons of an annual character. These silty layers cannot often be traced for more than a few feet horizontally, and may run up or down into a bed showing no lamination in a way suggesting cross bedding. Another very characteristic feature is the presence of half inch sheets of greenish impure siderite every two or three feet, though these are not found everywhere.

The silty layers with peaty substances when washed to remove clay and then dried and looked over with a lens show great uniformity in all parts of the region. Scales of mica are always numerous, as well as mosses, spruce leaves, certain round black seeds and chitinous portions of beetles. So constant is this assemblage that these clays are easily recognized by it when found in new localities, the clay ironstone sheets affording an additional earmark. Finally these are the only clays in the region which burn to a dark red brick. As their materials must have been derived by the Laurentian river and its tributaries from the calcareous bowlder clay of the valley to the north, much of the lime must have gone into solution by superficial weathering before reaching the river or have been dissolved during the time of transport, thus allowing the red color due to iron to appear on burning.

From the peaty layers of the clay the beetles were obtained whose names are given in the following lists :

[1] B. A. A. Sc. Rept., Com. on Pleistocene of Canada, p. 3.

Carabidae (9 gen., 34 sp.)
Elaphrus irregularis
Loricera glacialis
" lutosa
" exita
Nebria abstracta
Bembidium glaciatum
" Haywardi
" vestigium
" vanum
" praeteritum
" expletum
" damnosum
Patrobus gelatus
" decessus
" frigidus
Pterostichus abrogatus
" destitutus
" fractus
" destructus
" gelidus
" depletus
Badister antecursor
Platynus casus
" Hindei
" Halli
" dissipatus
" desuetus
" Harttii
" delapidatus
" exterminatus
" interglacialis
" interitus
" longaevus
Harpalus conditus

Dytiscidae (3 gen., 8 sp.)
Coelambus derelictus
" cribrarius
" infernalis
" disjectus
Hydroporus inanimatus
" inundatus
Hydroporus sectus
Agabus perditus

Gyrinidae (1 sp.).
Gyrinus confinis LeC.

Hydrophilidae (1. sp.).
Cymbiodyta exstincta

Staphylinidae (11 gen. 19 sp.).
Gymnusa absens
Quedius deperditus
Philonthus claudus
Cryptobium detectum
" cinctum
Lathrobium interglaciale
" antiquatum
" debilitatum
" exesum
" inhibitum
" frustum
Oxyporus stiriacus
Bledius glaciatus
Geodromicus stiricidii
Acidota crenata, Fabr. (*var.* nigra)
Arpedium stillicidii
Olophrum celatum
" arcanum
" dejectum

Chrysomelidae (1 gen. 2 sp.).
Donacia stiria
" pompatica

Curculionidae (4 gen. 6 sp.).
Erycus consumptus
Anthonomus eversus
" fossilis
" lapsus
Orchestes avus
Centrinus disjunctus

Scolytidae (1 sp.).
Phloeosinus squalidens

Dr. S. H. Scudder, who determined the beetles, thinks that all but two of the 72 are extinct. Twenty-five of the number were named a few years ago from Scarboro' material sent by Dr. Hinde, the rest more recently from specimens collected at various outcrops of the peaty clay by the writer. A complete account of the new species, with figures, will be published shortly by the Canadian geological survey. The number of species of beetles could no doubt be extended if the work of determining them were not so very laborious. In addition to the beetles cyprids occur and rarely also fragments of sphaeriums.

The plants include several trees, Professor Penhallow having found Larix americana, Picea alba and another species of Picea in materials from Price's and Simpson's brickyards; while Dr. Macoun found leaves apparently of willow and alder in peaty material from Scarboro', as well as two shrubs, Oxycoccus palustris and Vaccinium uliginosum, and some smaller plants, such as equisetum, Carex aquatilis and C. utriculata. Dr. Hinde reports five species of mosses belonging to the genera Bryum, Hypnum and Fontinalis; and Mrs. E. G. Britton adds Limnobium. Three species of diatoms, a chara and spores of lycopodium have been reported also.

Dr. Scudder judges from the relationships of the beetles to modern forms that the climate had "a boreal aspect, though by no means so decidedly boreal as one would anticipate under the circumstances." The same conclusion is reached by Dr. Macoun and by Professor Penhallow from the plant remains.

The change from the warm climate fauna and flora to the cool climate ones appears rather sudden, but may not be so in reality. The upper blue clay (No. 7) at Taylor's brickyard has yielded a caribou horn, which suggests a cooler climate than that of the trees and unios a few feet below, since no caribou are known within 150 or 200 miles to the north of Toronto at present. However, the range of the caribou toward the south may have been greater before the white man's settlements encroached on the region. On the other hand the materials of the delta deposits must have been derived largely from the regions to the north

and from a higher elevation, where at present some trees found in the Don valley are wanting, such as Platanus occidentalis, which reaches its northern limit at Toronto.

The peaty clay occupies the western part of the great bay into which the Laurentian river emptied when the interglacial lake was at its greatest height. It appears first at Rosebank, 16 miles east of the Don, and is last seen with certainty 2½ miles west of the river in a sewer on Bathurst street, making a width of 18½ miles. Dr. Hinde reports it also from the mouth of the Humber, 6 or 7 miles west of the Don, but the writer has not been able to find it there, though somewhat loesslike sandy silt containing a few plant remains, occurring near the Humber, may represent the peaty clay of Scarboro'. If so, the whole extent of the beds will be 25 miles from east to west. The last exposure known towards the north is 6½ miles inland from Lake Ontario, and no doubt if the cuttings of the Don were deep enough it would be found considerably farther north. The greatest thickness of the clay at Scarboro' is about 94 feet, 5 below the lake and 89 above; but the upper limit is rather hard to fix, since it becomes interbedded with sand. Toward the west the peaty clay rises higher, reaching 150 feet north of Reservoir Park and in the Bathurst street sewer.

INTERGLACIAL SANDS

Above the peaty clay at Scarboro' there are stratified sands with a thickness of 55 or 60 feet where best developed near the central part of the heights, following the lower beds conformably and apparently laid down in shallower water but under similar climatic conditions. The lower 4 or 5 feet have clayey layers, but above this the sand is quite coarse, through free from pebbles, and shows cross bedding in some layers. In the sand are found all the usual minerals of Archean rocks, and a few bands of garnet and magnetite occur, evidently arranged under wave action, as on the present beach at the foot of the cliff. Just over the peaty clay there is sometimes an accumulation of coarse woody material, flattened twigs, bits of bark, etc., with quite large

branches of Larix americana and Abies balsamea; and similar layers but in less quantity occur at a few points 20 or 30 feet higher up in cross bedded sand. Near the top of the sand numerous nut-like concretions of brown iron ore are found and occasionally also a few shells, such as Sphaerium rhomboideum, S. fabale, Limnaea sp., Planorbis sp., and Valvata tricarinata, but unios have not been obtained from them. The stratified sands were apparently laid down like the clays, from materials brought from the north by the Laurentian river, but in shallower water where wave action was effective, forming wide sand flats and largely filling the western side of the bay previously described. If they stretched eastwards toward the Pickering shore of the bay they must have been eroded afterwards, since they run out 8 or 9 miles from the river Don. That the stratified sand has undergone great erosion will be shown later. The sand is exposed for about 5 miles along the Scarboro' cliffs and is found overlying the peaty clay 6 miles west near Mt. Pleasant cemetery, so that it extends at least 11 miles.

A series of interglacial sands and gravels occurs in western Toronto and is well exposed in large pits near Christie and Shaw streets; but its exact relationship to the Scarboro' deposits is not certain. Where the two series meet near the corner of Dupont and Bathurst streets there are two or three beds of clay with peaty layers interstratified with sand, suggesting that the sand and gravel are of the same age as the Scarboro' clay. In the sewer opened at this point the only fossils found, beyond the remains of beetles, mosses, seeds, etc., from the peaty layers, are a few small bits of wood, which have not been determined, and the ulna of a mammoth or mastodon. The latter, however, may not belong to these beds, since it has been smoothed and scratched by glacial action, and may have lain on the surface at the time of the Wisconsin ice advance.

In the sand and gravel pits half a mile to the west no clay is to be seen and it is not certain whether the beds correspond to the warm climate period of the Don, or to the cool climate period of Scarboro', or include the equivalents of both periods.

At Mr. Adare's sand pit a considerable number of fossils have been obtained, including numerous campelomas, two or three species of pleurocera, Valvata sincera, two or more species of sphaerium, and fragments of unios, all shells which occur in the Don beds. Beside these fossils bits of elephant tusks and a large atlas vertebra, probably of Bison americanus occur, but none of the species is decisive as to climate, though the mammoth or mastodon suggests a cool climate.

The sand and gravel beds have a thickness of at least 78 feet and rise 130 or 140 feet above Lake Ontario, but their extent is unknown, as they are in general buried under bowlder clay. It is certain that these beds were formed under different conditions from those either of the Don or Scarboro'. They are of coarser and more variable materials, often showing very marked cross bedding, probably produced by currents rather than waves, and sometimes apparent unconformities such as are made by a stream changing its bed. We may suppose that an interglacial Humber river coming in from the west or northwest brought down sand and gravel at the edge of the great bay, mingling them at some points with the clayey delta materials of the Laurentian river.

This brings to a close the series of deposits composing the Toronto Formation. In all there are four varieties, the sands and clays of the Don with their warm climate trees and Mississippi unios; the peaty clays of Scarboro' with their seventy extinct beetles and their small flora, suggesting a cool, but not arctic climate; the stratified sands overlying them, probably forming a continuation of the cool climate period; and the western sands and gravels with elephants, bisons and some shellfish affording little evidence as to climate. The maximum thickness observed in each set of deposits is as follows:

3. Scarboro' sands - -	60 feet.	4. Western sands and gravels, 78 ft.
2. Scarboro' peaty clays	94 "	
1. Don beds - -	41½ "	
	195½	

The greatest thickness measured at one place is at Scarboro'

Heights where 150 feet of cool climate beds overlie 36 feet of warm climate beds, making 186 feet in all. However as the 36 feet of unio sands and clays commence 5 feet below the level of Ontario and its water filled the well sunk there before the bowlder clay was reached, it is certain that the Scarboro' section contains more than 186 feet of interglacial beds, but how much more cannot be told. It is probable also that the upper sands once reached higher than at present, since their surface evidently underwent great erosion before the overlying bowlder clay covered them.

DRAINING OF THE SCARBORO' LAKE

At its highest point the great interglacial lake must have stood more than 150 feet above Ontario, since the upper beds of the cold climate deposits reach 152 feet. Then came a fall in the level, whether sudden or slow is uncertain, though a slow drainage seems more probable. The cause of the original rise of the water was probably the elevation of the lower part of the Laurentian river valley, near the Thousand Islands. If so we may suppose that the rise of the northeastern portion of the continent was slow, as it is at present ; and it may not have gone on at a uniform rate, for there seems to have been a halt at 60 feet above the present lake. If the rise was slow the sinking of the barrier at the Thousand Islands at the close of interglacial times was probably equally deliberate. Ultimately the water fell below the present level of Ontario, as shown by the erosion of interglacial valleys in the strata of the Toronto Formation; but whether the lake was completely drained so as to restore the open valley with its great river or was only partially drained is uncertain.

With the lowering of the lake the channels of the rivers must have been rearranged, for the old bay was now largely filled with clay and sand ; and in the Scarboro' section there is evidence of the cutting of three valleys through the stratified sand and peaty clay. The one to the east, where the River Rouge and Highland Creek now flow, was cut down below the

present level of lake Ontario for about five miles, probably by the Laurentian river, which seems to have shifted its bed towards the east as the lake level sank, to avoid the thickest part of the previously formed delta. As no peaty clay has been found in the cuttings made by the Rouge and Highland Creek, but only bowlder clay and later stratified clay and sand, this interglacial valley seems to have been extensive.

Walking westward from Highland Creek the slope of the old valley is seen to rise gently, first the peaty clay showing above the water and becoming thicker and thicker, and then the overlying sand showing itself, finally reaching its maximum thickness about four miles from the first appearance of the peaty clay on the lake shore. How much of the valley already existed before the river began its work is unknown, but at least a considerable thickness of the tough peaty clay must have been cut through, for at Rosebank to the east of the old valley it rises 20 or 30 feet above the lake.

Continuing westward along the shore a second much narrower valley still buried under till and unfossiliferous stratified clay is seen at the "Dutch church," as a vertical promontory three miles from the western end of the Scarboro' section has been called. This "fossil" valley was cut through the full thickness of interglacial sand and clay to a level below the present lake, on the shore of which it shows a width of about 1200 feet. At the top of the peaty clay, 90 feet above the lake, its width is about double this; and its sides then slope gently up to the top of the stratified sand with a total width not much short of a mile. The Dutch church valley was apparently made by a comparatively small stream.

It should be mentioned, however, that Professor Albrecht Penck gives another explanation of the downward dip of the bowlder clay at this point, supposing that the promontory is really a mass of till lodged to the south of an old lake cliff of interglacial times. The old cliff has been exposed again on each side of the Dutch church by the action of the present lake, but the tough clay at that point has resisted better and still remains.

According to this view, after the Scarboro' beds were deposited the water sank to a level below that of the present lake and remained there long enough to cut back the mass of delta deposits to about the position of the present cliff. Although the first explanation seems the more simple, the one given by Professor Penck deserves careful consideration. At present there is not evidence enough to settle positively which is correct.

Toward the west of the Scarboro' exposure the stratified sand gradually thins and disappears beneath the bowlder clay and the same is afterwards true of the peaty clay, which sinks below the lake at Victoria park at the east end of Toronto. Here probably another wide valley was cut, though its western shore is not seen distinctly. The upper stretch of the Don Valley, which turns to the east after emptying into Toronto Bay, discloses only till and the overlying unfossiliferous beds in its ravines, though peaty clay rises to 152 feet near Mount Pleasant cemetery toward the west, and to nearly 100 feet at Price's brickyard to the southeast, suggesting an old river valley between, perhaps of an interglacial Don. The form of this valley is not so well worked out, however, as in the case of the other two.

As no interglacial deposits have been found clearly belonging to this later low water stage, there is no evidence as to the climate during the latter part of the interglacial time; but we may suppose that it grew colder until the region was once more covered with an ice sheet, probably corresponding to the Wisconsin till of the states to the southwest.

LATER GLACIAL DEPOSITS

The earlier (Iowan) ice advance found little obstruction in the region of Toronto and passed over leaving only a comparatively thin sheet of bowlder clay, not greatly modifying the general form of the surface; but the later glacial invasion took place under changed conditions. The broad Georgian Bay — Scarboro' Valley through which the Laurentian river had flowed, was now largely blocked with the great interglacial delta deposits, which no doubt stretched as a tongue some miles in length

out into the valley of the present Lake Ontario. The lower part of these deposits consists of very firm stratified clay strengthened by sheets of clay ironstone; but at the eastern end of Scarboro' Heights the clays have been greatly crumpled and contorted, and even large blocks shifted and tilted, by the pressure of the on-coming Wisconsin ice. As the delta seems to have run about southeasterly it lay almost directly athwart the course of the advancing ice, which, after crossing the later valley of the Laurentian river, had to climb over a ridge at least 150 feet in height, and probably considerably higher, before proceeding on its way diagonally across the Ontario Valley. This obstruction, perhaps aided by climatic variations, seems to have kept the ice more or less in check. Meantime the lower end of the Ontario Valley must have been blocked with ice so that the water once more rose assorting the "rock flour" furnished by subglacial streams as gray stratified clays without fossils overlying the uneven surface of bowlder clay covering the series of ridges and valleys left by the interglacial rivers.

The halt at the Scarboro' delta was long and must have included at least three great oscillations of retreat and advance to account for the complex of tills separated by stratified materials now crowning the heights. The first sheet of till is shown for about nine miles continuously at Scarboro' with the shape of a slightly bent bow, touching the lake at each end and with a sharp downward dip at the Dutch church. The latter is, however, less symmetrically placed than in a bow, being only three miles from the west end and six from the east.[1] The hollow of the Dutch church valley was filled with till containing comparatively few stones to a level 50 or 60 feet above the present lake, then merging into gray stratified clay which rises to a height of 165 feet, where it is covered with a few feet of much later Iroquois beach gravel. Very similar clays rising to the same height or a little higher are found at brickyards to the north of Toronto. They burn to a gray brick and so are

[1] See diagram, JOUR. GEOL., Vol. III, No. 6, 1895, p. 624.

easily distinguished from the peaty clay which makes red brick.

The highest part of the Scarboro' escarpment, about a mile east of the Dutch church, gives the best section of these complex glacial deposits. At the point where the old Iroquois beach is cut off for a distance by the present lake cliff, there is a face of 270 feet displaying three layers of bowlder clay separated by stratified sand, the whole overlying the stratified fossiliferous sands of the Toronto Formation. A few hundred yards to the east of this the escarpment reaches its highest level, 354 feet above the lake, but the lower part is not so well shown. The upper portion is, however, more complete, since overlying the third till sheet one finds laminated grayish blue or purplish clay followed by evenly bedded fine sand, on which rests a fourth bowlder clay. Putting the two sections together we have the following complete section:

	Feet	
Bowlder clay No. 4	48–354	203 feet Glacial Complex
Stratified sand overlying stratified clay	36–306	
Bowlder clay No. 2	32–270	
Silty sand, the upper layers crumpled	25–238	
Bowlder Clay No. 3	9–213	
Cross bedded sand	29–204	
Bowlder clay No, 1	24–175	
Fossiliferous sand	59–151	151 feet, Toronto Formation
Peaty clay	92– 92	
Lake Ontario	0	

The whole series of tills with the interstratified sand and clay at Scarboro' amounts to 203 feet in thickness and implies a glacially dammed lake reaching more than 300 feet above Ontario. The highest stratified materials in the neighborhood of Toronto occur, however, at the North Toronto waterworks, 360 feet above the lake, where a well showed several beds of clay alternating with sand and gravel, probably equivalent to some of the beds at Scarboro'.

No fossils have been found in the sands or clays of the glacial complex at Scarboro', but a few have been picked up in stratified sand lying between two beds of bowlder clay at the

Metropolitan power house, a mile or two north of Toronto, Amnicola limosa, a Succinea and fragments of another species. These occur at 220 feet above the lake, but the sand containing them runs up to 247 feet and may correspond to the silty sand between till No. 2 and till No. 3 at Scarboro'.

One of the recessions of the ice, perhaps the one just mentioned, appears to have been very extensive, for two thick beds of bowlder clay are found to be separated by stratified materials at numerous points on the lake shore as far east as Newtonville, fifty miles from Toronto. The same relationship is found near the headwaters of the Don, about eight miles north of the city, and also in ravines to the east, but has not been observed to the immediate west; though the stratified clays lying between two layers of till at Dundas and at several points near Niagara Falls may correspond to the same interglacial stage. In that case the ice must have withdrawn eighty miles in a northeasterly direction before advancing again.

During the first recession of the ice the lake was dammed to a level at least 160 feet above the present, for roughly stratified grayish clay with a few small polished and striated stones is found at many points at about this level, filling in hollows of the bowlder clay, as at the Dutch church and Taylor's brickyard. Afterwards, as shown above, the water stood much higher, since stratified materials are found 360 feet above Ontario or 606 feet above the sea, and may have formed part of a large body of water, covering Lake Erie as well as the western end of Ontario. As the whole of these stratified clays and sands were afterwards overridden by the ice and covered with the latest sheet of till they must be looked on as interglacial. The highest bowlder clay has not yet been traced with certainty west or south of the Toronto region, however, since the four sheets of bowlder clay are very much alike and cannot be discriminated when found alone; and there is a possibility that it ends here, and that the water then filling the Ontario basin was continuous with that of some of the successors of Lake Warren. If so, beach lines may have been formed to the west or south of Lake Ontario while

the last till was being spread over the upper interglacial beds here described. Professor Fairchild places the Warren beach south of Lake Ontario at 880 feet, and his next important water level, Lake Dana, at about 700 feet, both far above the highest interglacial stratified sand or clay at Toronto.[1]

CONCLUSIONS

One who studies the complex set of glacial and interglacial beds of the Toronto region is strongly impressed with the length of time demanded for their production. There is no reason to suppose that the withdrawal of the Iowan ice and the drainage of the waters which it dammed were more rapid than the similar series of events following the latest ice sheet. When the Toronto beds began to be formed the water level in the Ontario valley was probably lower than now in Lake Ontario, and some erosion had already taken place in the Don valley and at other points. There had been time for the warm climate plants to return from exile in full force and for forest trees of a most varied kind, though mainly deciduous, to grow and fall on the banks of the rivers. The unios, too, had already migrated north from the Mississippi stronger in species than they are now. All this may imply as long a time after the Iowan ice sheet withdrew as has elapsed since the last ice sheet departed, before the lowest beds of the Toronto Formation were even begun.

Then came the raising of the rocky barrier at the eastern end of the Ontario basin to sixty feet above the present level, and a halt at that level while the upper sands became browned and cemented with limonite. The climate grew cooler and and then ninety-four feet of clay and fifty-five feet of stratified sand were laid down at Scarboro', the eastern barrier rising meantime to 152 feet above the present level.

Then there was a halt in the elevation toward the northeast and at length a reversal of the motion, the northeastern end of the basin being depressed until the great Scarboro' lake was drained to a level probably much lower than that of Ontario at

[1] Bull. Geol. Soc. Am., 1899, p. 31 and p. 56.

present, and river valleys were eroded through 150 or 250 feet of sand and clay and widened so as to have gentle slopes.

It will be observed that the damming of the interglacial waters is held to be due to epeirogenic changes and not to the presence of ice, since it is inconceivable that an ice dam should hold its place at the Thousand Islands during the ages of mild climate required for the growth of the luxuriant Don forests, largely composed of trees that now barely reach the southern edge of Canada.

It is not unfair to assume that the time after the Iowan ice retreated until the commencement of the Toronto Formation was as long as from the retreat of the Wisconsin ice to the present, a time variously estimated at from 7000 to 30,000 years. The raising of the northeastern barrier of the Scarboro' lake to a height at least 150 feet above that of Lake Ontario may also have required thousands of years, if the results of Dr. Gilbert's investigations as to the rate of tilting of the present lake basins furnish the standard. These two stages cover only the first half of the interglacial time, and probably an equal number of thousands of years were required for the depression of the outlet below that of Lake Ontario and the cutting of wide and deep valleys through the Toronto Formation.

To arrive at the total length of the interglacial period it is not extravagant to double or even triple the number of years since the last Ice age, giving estimates of from 14,000 to 60,000 years or more. It will of course be understood that the length of time since Niagara began to cut its gorge can be estimated only vaguely and that the guess at the length of the interglacial period given here is still less certain.

How long a time the later series of bowlder clays and interstratified materials, more than 200 feet thick at Scarboro', required in their formation one can hardly even guess; but one of the glacial retreats amounted probably to more than 50 miles and may alone have demanded centuries of recession and advance.

The time element in the series of events described has been

somewhat strongly insisted on in this paper, since many geologists who have worked only in regions where the Pleistocene deposits are relatively simple in structure and not of great thickness are apt to underrate the importance of interglacial periods, looking on them as short episodes of retreat and advance in the history of a single Ice age. The evidence adduced here points to completely distinct Ice ages, separated by thousands of years of mild climate. It is not improbable that the present time is merely another interglacial period.

An interesting result of the action of rivers and ice is found in the change of relief in the region since the Iowan ice departed. The valley of the Laurentian river, then probably a hundred feet or more below the present level of Lake Ontario, is now replaced by Scarboro' Heights rising 350 feet above the lake and presenting the highest cliffs on its whole shore.

A summary of the best marked stages in the Pleistocene history of the region is given below, special reference being made to climates and water levels. The latter are of course not absolute levels but only relative, since the region as a whole probably underwent important elevations and depressions during Pleistocene times.

STAGES OF TORONTO PLEISTOCENE

1. Retreat of the Iowan ice sheet.
2. Interval of erosion with water probably lower than at present.
3. Don stage, warm climate trees and Mississippi unios, water dammed by differential elevation toward the northeast to 60 feet above the present lake.
4. Scarboro' peaty clays, cold temperate climate, with trees and mosses and 70 species of extinct beetles, formed as delta by Laurentian river in interglacial Scarboro' bay.
5. Scarboro' stratified sand with some trees and freshwater shells of cold temperate climate, delta completed, lake stands 152 feet above the present.
6. Water drawn off by lowering of outlet, subaerial erosion of previous beds, and cutting of river valleys more than 150 feet deep.
7. Advance of Wisconsin ice front raising the water to about 160 feet as shown by stratified interglacial clay, retreat for 50 miles and re-advance, followed by two later retreats and advances, the water finally rising 360 feet above the present lake.
8. Final retreat of ice sheet, followed by water levels of lakes Warren and Iroquois and a brief entry of the Gulf of St. Lawrence into the Ontario basin, which, however remained fresh.

A. P. COLEMAN.

PROBABLE REPRESENTATIVES OF PRE-WISCONSIN TILL IN SOUTHEASTERN MASSACHUSETTS

INTRODUCTION

In the central portion of the country, where the glacial deposits are spread out in a general northward retreating series of sheets, the tills of the various ice invasions have long been differentiated and classified chronologically with a considerable degree of certainty. In New England, however, each of the prominent advances reached nearly or quite to the southern limit of the area. The repeated passage of the ice over the region, and the consequent severe glaciation to which it has been subjected, has served to remove far more thoroughly than in the region further west the evidences of pre-Pleistocene conditions and of early Pleistocene tills. Under such conditions of glaciation, the preservation of remnants of the early tills would be very exceptional, and it is not strange, therefore, that deposits of these early tills have not previously been found.

While severe glaciation is the rule in New England, the action has by no means been of the same severity throughout the area. The area may be divided into three parts: (1) a northern belt characterized by severe and almost universal erosion with correspondingly little deposition; (2) a middle belt with generally moderate, though sometimes locally severe glaciation, but characterized as a whole by a marked deposition of subglacial till as attested by its drumlins; and (3) a southern belt of generally weak erosion, except in the more exposed localities, accompanied by a comparatively slight deposition of till. This southern belt, the northern limit of which in eastern Massachusetts is a few miles south of Boston, is nearly or quite destitute of drumlins, rarely shows any evidences of severe glaciation such as characterizes the northern belt, and is marked by the occurrence of numerous instances of pre-glacially decayed rock surfaces.

It was while engaged in field work on the surface geology of

this southern belt that the writer first encountered exposures of till of a type entirely unlike that ordinarily prevailing over this part of New England. In composition, in color, and in weathering, the till in question was strikingly different from the ordinary buff till of the region, and had the aspect of being much older than the latter. A further study of its character and associations was found to corroborate the differences first noted, and apparently warranted the conclusion that it should be considered as representing the deposits of an ice sheet which certainly antedated the last invasion, and probably marked the earliest of the Pleistocene advances.

The area embracing these tills is located in the eastern and central portions of the Dedham quadrangle of the United States geological survey at a distance of some twenty miles south of the city of Boston. The position of the quadrangle and of the area of the till localities is shown in Fig. 1.

It will be seen from this map that the tills are situated some fifteen to twenty miles inside of the interlobate moraine near Plymouth, and at a distance of some fifty miles north of the line of the corresponding terminal moraine. This moraine, for in origin it is a unit, is usually correlated chronologically with the Wisconsin. If this is so, and there are apparently no grounds for doubting the conclusion, it is evident that the till sheet which covers the surface of this portion of Massachusetts to an average depth of perhaps five to fifteen feet, and which is clearly contemporaneous with the moraine, is likewise of Wisconsin age.

Observations on Massachusetts glacial deposits of an age earlier than those of the last ice advance have been few in number and, with the exception of occasional instances of the burial of stratified drift deposits beneath later tills, have been confined to the vicinity of the moraines along the south coast where the conditions for differentiating the glacial deposits are more favorable than in the inland area to the north.

Before considering the evidences of older tills which the writer believes he has discovered beneath the Wisconsin till sheet, mention will be made of a number of papers presenting

evidences of possible interglacial phenomena or of plural tills in this part of New England.

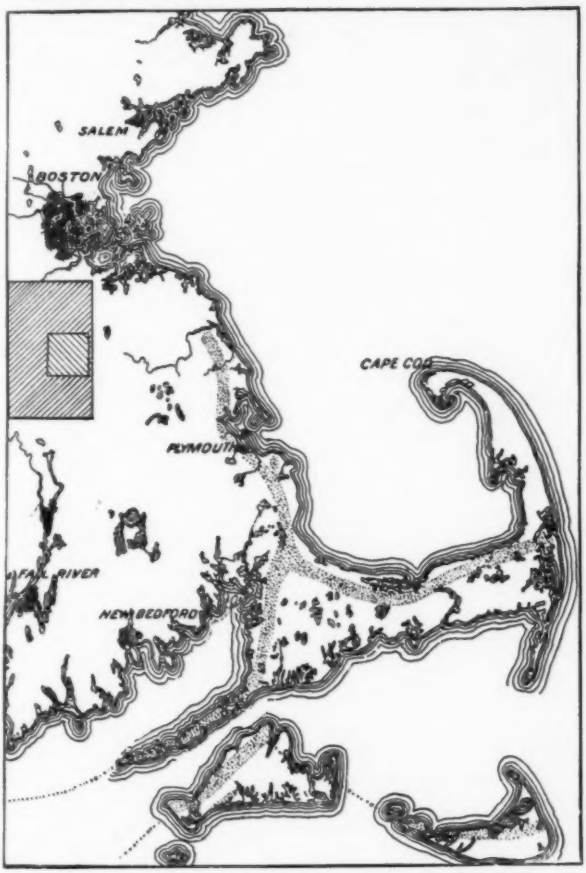


FIG. 1.—Sketch map of southeastern Massachusetts, showing the location of the Dedham quadrangle and of the special map of till localities (Fig. 2).

One of the first papers describing occurrences suggestive of interglacial deposits was that published by W. W. Dodge[1] in

[1] Some Localities of Post-Tertiary and Tertiary Fossils in Massachusetts. Am. Jour. Sci., Series III, Vol. 36, pp. 56, 57.

1888. Though not recognizing the true nature of the material, he described a section of the Great Head Drumlin of Winthrop, a few miles northeast of Boston, and showed that beneath the great mass of clayey material, now known to be till, it possessed a core of fine loose gravel rising several feet above the base of the section (sea level), and containing fossil fragments of Venus mercenaria and other species identical with those existing in the waters of the harbor at the present time.

In 1888, Upham[1] also referred to the presence of the core of modified drift in the drumlin at Great Head, Winthrop, and announced the presence of similar cores in drumlins at Third and Fourth Cliffs at Scituate, some twenty-five miles southeast of Boston. No evidence as to age was brought forth beyond the fact that the stratified deposits were of glacial origin and antedated the ice advance, supposedly the last by which their till coating was deposited.

Shaler[2] was probably the first in Massachusetts to call attention prominently to the occurrence of two distinct tills separated by a long interglacial period. According to him the deposition of the oldest formation of Nantucket, which he describes as a blue pebbly clay till was followed by a long period of submergence and the deposition of fossiliferous marine beds, after which the ice again advanced, partly eroding the marine beds and giving rise to the well-known morainic deposits of the north shore of the island.

In his paper on the "Structure of Drumlins"[3] Upham, in 1899, gave a detailed description of the drumlins of Third and Fourth Cliffs at Scituate and illustrated the descriptions by sections, one of which showed the presence of till both above and beneath the stratified core of the drumlins. The section apparently demonstrated that the stratified deposits were interglacial, at least in the narrow sense of the word, for they were evidently

[1] Marine Shells and Fragments of Shells in the Till near Boston. Boston Soc. Nat. Hist. Proc., Vol. XXIV, pp. 127-132.

[2] The Geology of Nantucket, U. S. Geol. Surv., Bull. 23.

[3] Boston Soc. Nat. Hist., Proc., Vol. XXIV, pp. 228-242.

deposited between an earlier and a later ice advance. The two tills, however, were identical in character, and presented nothing indicative of any considerable time interval between their deposition. The tills and the included stratified drifts are probably to be regarded simply as marking local variations of the same general invasion. Drumlins in which layers of modified drift are inclosed in the till were also mentioned as occurring in other parts of Massachusetts and in New Hampshire and New York.

The descriptions of the drumlins at Scituate were repeated by Upham in 1894 in his paper on the "Madison Type of Drumlins,"[1] but no new facts of importance bearing upon glacial conditions in Massachusetts were presented.

In the table and descriptions accompanying his paper on the clays of Rhode Island and southeastern Massachusetts Woodworth,[2] in 1896, gave three glacial epochs. The first and second were separated by the deposition of the fossiliferous marine gravels, sands, and clays of the Sankaty sub-epoch, as was recognized by Shaler on Nantucket. The second ice invasion, which is apparently assumed (p. 977) as the cause of the strong folding of the Cretaceous, Tertiary, and early Pleistocene strata of Gay Head, etc., and the last invasion are separated by what is designated as the Vineyard interval of extensive subareal erosion, accompanied by deposition below the present sea level.

In the chapter on the clays about Boston, Marbut and Woodworth[3] give reason for believing that the clays were probably of esturine or marine origin, and were deposited in connection with a previous ice invasion. Several sections are described and illustrated which show that the clays are in a number of cases overlain by drumlins which were formed during the last ice advance. The clays frequently present evidences of strong erosion, probably due largely to the action of over-riding ice

[1] Am. Geol., Vol. XIV, pp. 69–83.

[2] The Glacial Brick Clays of Rhode Island and Southeastern Massachusetts: The Geology and Geography of the Clays. U. S. Geol. Surv., Seventeenth Ann. Rept., Pt. I, pp. 975–988.

[3] Loc. cit., pp. 989–998.

(p. 991). According to the evidence presented, the clays are contemporaneous with an earlier ice advance, and are clearly older than the last, but nothing definite as to the length of time intervening is known.

In 1898, Shaler in his paper on "The Geology of the Cape Cod District,"[1] again recognized the existence of two tills, between the deposition of which a period of great length intervened. In this interval he recognized the deposition of three sedimentary formations:[2] the Nashaquitsa, the Barnstable, and the Truro, each of which was followed by prolonged periods of aqueous erosion. This interglacial time was regarded as vastly longer than that which has elapsed since the disappearance of the ice of the last invasion.

DESCRIPTION OF TILL EXPOSURES

The ordinary till exposures in southeastern Massachusetts present the following characteristics. At the top lies a light buff till consisting of the usual heterogeneous mass of clay, sand, and bowlders. The percentage composition of this till varies within wide limits, especially in regard to the quartz-flour and clay constituents which range from a combined amount of perhaps 10 per cent. or less in some of the tills in the southern portion of the state to an average total of some 55 per cent. in the drumlins about Boston.[3] In most sections the till is moderately oxidized from top to bottom, as indicated by its buff color, but where natural or artificial cuts have exposed it to any considerable depth it is found to pass downward into an unoxidized portion of a gray or bluish-gray color, usually designated as blue till. The depth to which the oxidation extends presumably depends somewhat on the percentage of the clay constituent of the till. Though the oxidation is very much less conspicuous in tills high in sand, the depth to which the oxidation extends is probably

[1] U. S. Geol. Surv., Eighteenth Ann. Rept., Pt. II, pp. 497–593.

[2] Loc. cit., pp. 535–538.

[3] W. O. CROSBY: Composition of the Till or Bowlder Clay. Boston Soc. Nat. Hist. Proc., Vol. XXV, p. 25.

greater than in the more clayey tills. In the Boston drumlins, which are high in clay, the oxidation has usually reached a depth of some twenty feet. Where the bedrock upon which the tills rest is exposed to view it is ordinarily found to present well glaciated surfaces, showing no traces of decomposition beyond a thin superficial zone seldom more than half an inch in thickness, and often represented only by a slight surface discoloration.

CENTER STREET EXPOSURE, BROCKTON

In marked contrast to the section just described are the sections exhibited by the older tills observed by the writer. The first of these old tills to be observed was exposed several years ago during excavations for the foundations of one of the heavy stone arch bridges which were necessitated by the abolishment of the grade crossings of the New York, New Haven and Hartford Railroad. (Fig. 2, Exposure 1.) The first six feet or so from the surface was of the ordinary slightly oxidized buff till of the last, or Wisconsin invasion, but on going deeper, instead of becoming lighter and gradually merging into the unoxidized blue till as in the ordinary typical section, the buff till gave place abruptly to a mass of distinctly red and yellow till. This till at the time it was seen by the writer was exposed to a depth of about four feet, but was later excavated to a depth of from two to four feet more, at which point it was found to rest on a deeply decomposed and highly oxidized conglomerate of Carboniferous age. Besides its high colors, due to the advanced state of oxidation, the lower till was found to differ in a marked degree in composition from the ordinary buff till. Clay, including quartz-flour, which in the overlying till forms less than one half of its bulk, constitutes nearly the whole of the lower till. The pebbles of the upper till comprise some 25 per cent. or more of its mass and are varied in type, complex in composition, fresh in appearance, and have often been transported considerable distances. In the lower till, on the other hand, the pebble component probably never exceeds 10 per cent. of the mass, and only the resistant quartz and quartzite pebbles from the underlying

rock are usually represented. The buff till is without visible structure, while the lower oxidized till is characterized by a distinct, but rude and highly irregular lamination.

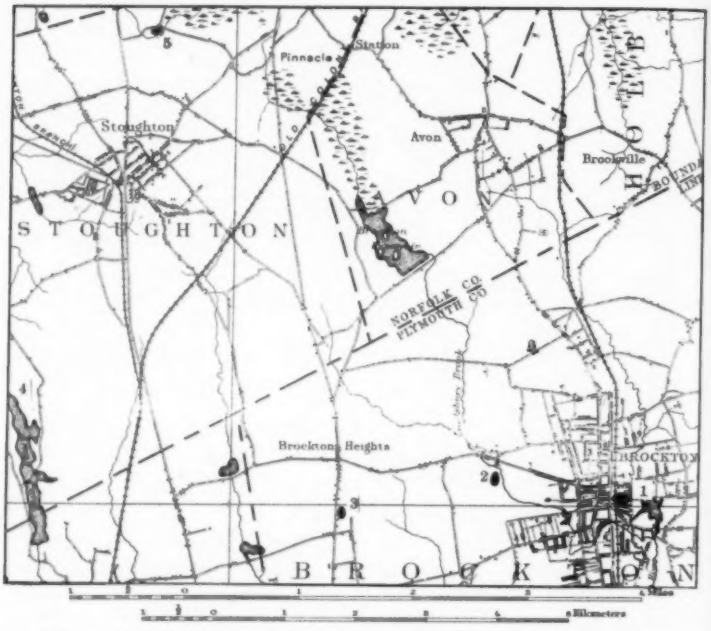


FIG. 2.—Map[1] showing location of exposures of tills of probable Pre-Wisconsin age. 1. Center street exposure, Brockton; 2. Intervale Park exposure, Brockton; 3. Pearl street exposure, Brockton; 4. Ames pond exposure, Stoughton; 5. Pine street exposure, Stoughton.

The derivation of the lower till from the underlying decomposed conglomerate is plainly indicated by its color and composition. This conglomerate is composed largely of pebbles of granite, black slate, quartzite, and some quartz,[2] embedded in a

[1] Reproduced from special edition of the Dedham quadrangle of the U. S. Geological Survey. Presented through the courtesy of Professor W. O. Crosby and the Boston Society of Natural History.

[2] Quartz also occurs in considerable amounts in the numerous small veins cutting the conglomerate.

somewhat feldspathic sandy matrix. It exhibits a rather perfect cleavage at right angles to its stratification. Where so situated as to be exposed to the full action of the ice at the time of the last invasion, it exhibits smooth, hard, and well glaciated surfaces of a dark gray color with almost no evidences even of superficial oxidation. In less exposed positions, such as exist along the well defined valley running southward through the city of Brockton just east of the center, the glaciation was apparently exceedingly slight. It is in such positions that the decayed conglomerate from which the lower till was derived is found. At the surface the conglomerate presents the high colors of advanced oxidation, but somewhat irregularly arranged owing to variations of the original composition of the rock. Some of the portions free from iron give on decay spots or streaks of an almost white sandy clay. The predominating color is a distinct yellow, interspersed with red in many places. The rock is so soft at the surface that it can sometimes be removed by pick and shovel. The depth of the extreme decay is somewhat variable, possibly averaging from two to three feet, though it is probably considerably greater in places. From the highly decayed portions, the rock passes downward by insensible gradations into less altered portions, but in none of the shallow excavations which the writer has seen has fresh rock, such as is exposed where the glaciation has been severe, been reached. The decomposed conglomerate probably underlies most of the low region near the center of the city and has been exposed in the laying of water pipes, drains, sewers, etc., along Center and Crescent streets and near the high-school building on Main street. Many of the excavations in which decomposed conglomerate was exposed were made ten or more years ago, and though the presence of the decayed rock can be vouched for, the writer cannot say with certainty that it was everywhere overlaid by the oxidized till, though later observations suggest that such was probably the case.

It is certain that the deep rock decay antedates the last ice invasion. If this decay is the result of pre-Pleistocene weathering,

the evidence naturally leads to the conclusion that the overlying oxidized till evidently derived from it was the result of the re-working of the soft decomposed material by the first ice advance, in which case it is probable that it should be correlated with the Kansan or pre-Kansan glacial deposits of the central portion of the country. If, on the other hand, the rock decay is considered as of interglacial origin it constitutes of itself an evidence of a long interglacial period. This last supposition, however, cannot be maintained, for the rock weathering is far too extensive, reaching downward as it does to a depth of some feet, to have been brought about in interglacial times.

An alternative supposition which naturally suggests itself is that the oxidized till may after all be considered as of Wisconsin age, and as representing the re-working of the pre-Pleistocene decomposed rock material which had somehow been preserved from the erosive action of the earlier invasions. In answer to this it may be urged that, while the actual erosive power of the earlier advance was comparatively slight, it is almost impossible to conceive of an ice sheet so weak that at a point more than fifty miles from its margin it passed over soft decomposed rock material without re-working it in any degree, especially as till deposits of the corresponding advance occur along the outer margin at Nantucket sixty miles further south. A further and apparently fatal objection to the consideration of the oxidized till as of Wisconsin age lies in the fact that, in the re-working of the previously decayed rock and soil by a sheet known to be specially characterized by numerous foreign fragments, there would at least be a gradual transition between the highly oxidized and the ordinary type of till. In reality, however, the contact is so sharp that the breadth of a hand will usually, and sometimes more than cover it.

INTERVALE PARK EXPOSURE, BROCKTON

At the time of the laying out and leveling of the tract of land known as Intervale Park, about a mile west of the Center street locality, a number of good sections of till were transiently

exposed. One of these sections (Fig. 2, Exposure 2) showed a yellow and red oxidized till, almost identical in appearance with the one previously described and lying in a corresponding position beneath the ordinary buff till. The general character of the exposure is shown in Fig. 3, in which the horizontal and vertical scales are the same.

In composition the lower till was similar to that of the Center street exposure, being probably as high as 70 or 80 per cent. in clay and quartz flour. Like the first, it was evidently derived from the underlying conglomerate and showed the same quartzite pebbles and the same yellow and red colors. The prevailing

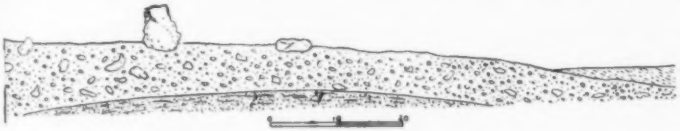


FIG. 3.—Section showing the relations of the older and younger tills in the Intervale Park exposure, Brockton. (Exposure 2 of Fig. 2.)

color, however, was somewhat lighter, yellow and gray predominating. Like the Center street exposure it was irregularly laminated and separated from the overlying till by a sharp and distinct line of demarcation.

With a view to comparing with other tills, samples of the oxidized till were collected and examined as to their composition. In the following table the results of the examination are given and compared with the immediately overlying till, and with the till of drumlins in the vicinity of Boston:

	Bowlders and gravel	Sand and quartz flour	Clay
1. Highly oxidized clay-till [1]	10	68	21-23
2. Ordinary till overlying the above [2]	50	45	5
3. Clay-till of Boston drumlins [3]	25	63	12

Attention is especially called to the clay constituent which in the lower till is about four and a half times as great as in the

[1] Clay determined chemically, others estimated from physical examination.

[2] Estimated from physical examination.

[3] Average of sixteen careful physical analyses by W. O. CROSBY, Boston Soc. Nat. Hist., Proc., Vol. XXV., p. 124.

overlying till and nearly twice that of the tills of the drumlins, which represent the most clayey tills previously known. The difference in the amount and character of the included rock material is also very marked. The lower till was found to contain only about 10 per cent. of pebbles, mainly under an inch in diameter and consisting principally of quartzite. The upper till contained some 50 per cent. of pebbles and cobbles, besides a large number of massive bowlders of granite and diorite varying from five to ten or even twenty feet in diameter.

The underlying rock was not exposed in the immediate vicinity of the till here described, but it is known to be a conglomerate similar in character to that of the Center street locality, and to be likewise considerably decomposed.

The great dissimilarity of the lower till from the overlying till, the sharp line of demarcation between the two, the evident derivation of the former from deeply decomposed conglomerate, and the exceptionally close resemblance of the lower till to that of the Center street exposure, have led the writer to correlate it with the latter and to refer it to the same early Pleistocene invasion.

PEARL STREET EXPOSURE, BROCKTON HEIGHTS

The writer's attention was called to this exposure of what may probably be considered as a representative of pre-Wisconsin till by Mr. M. S. W. Jefferson, of Brockton, to whom the credit of the discovery of the locality is due. The exposure was within a gravel pit of some size on the south side of Pearl street, a short distance north of its junction with Rockland street (Fig. 2, Exposure 3).

The height of the section was about five feet, of which the upper two feet was of the ordinary type of buff till containing numerous bowlders. The lower three feet was of an entirely different and somewhat remarkable character, being composed of an arkose-like mass of disintegrated material evidently derived from the coarse porphyritic granite which is known to underlie it. At first sight it bears a slight resemblance to a granite disintegrated *in situ*, but a closer examination reveals the presence

of sand and pebbles of foreign material, showing that it is to be regarded as a true till in which, as in the two tills already described, the material is almost entirely derived from the underlying rock. The color of the mass is a dirty, somewhat rusty brown, there being no trace of the higher colors exhibited by the tills previously considered. The line of demarcation between the two tills is much less sharp than in the preceding instances and is due to the predominance of the same granitic material in both tills. The chief difference is that in the lower till the granite is present as a disintegrated arkose-like mass, while in the

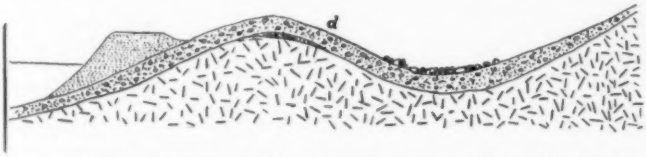


FIG. 4.— Section showing general relations of granite, till, and drift terrace at the Ames Pond exposure, Stoughton. Vertical scale, about 200 feet to an inch; horizontal scale, about 50 feet to an inch.

upper till it occurs in a fresh condition and largely as glaciated pebbles or bowlders.

AMES POND EXPOSURE, STOUGHTON

This exposure is in a gravel pit on the east side of the pond north of the small bay which comes up to the highway (Fig. 2, Exposure 4). The general section of the locality is shown in Fig. 4. The till to be described is exposed on the east slope of the rock and till ridge at *d*.

The lower till is somewhat similar to that in the Pearl street exposure at Brockton Heights, the material being a pink granite. The chief point of difference, perhaps, lies in the fact that the till of the Ames Pond exposure appears to have been originally a bowldery till, the fragments of which in most cases have subsequently completely disintegrated. The disintegrated granitic material probably constitutes ninety or ninety-five per cent. of the mass, and is apparently of local origin since a knob of similar granite projects through the till a short distance to

the north. There are a few pebbles of a fresher, though still distinctly weathered granite dispersed sparingly in the till. The difference in the extent of the decay is probably to be explained by the fact that the process which subsequently brought about disintegration were, in the larger portion of the material, well under way at the time of the ice advance, though actual disintegration may not have taken place until long afterwards. The fresher fragments were probably derived from portions of the ledges from which the more highly decomposed material had previously been removed. The thickness of the lower till as exposed in the gravel pit is about four or five feet. The color of the till is slightly darker than the overlying buff till, but the distinction is not marked.

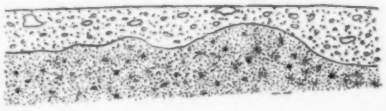
The upper till is composed of a heterogenous mass of material in which the same pink granite predominates, but with a considerable intermixture of foreign material. Its line of demarcation from the lower till is well defined, but, as would be expected from the fact that granite is the predominating material in both cases, is not so sharp as in the first two of the Brockton tills. All fragments of the upper till are fresh and usually present well glaciated surfaces.

PINE STREET EXPOSURE, STOUGHTON

The gravel pit in which was found the last of the tills to be described is located on the south side of Pine street at its junction with Pleasant street near the northern boundary of the town (Fig. 2, Exposure 5). The cut was about fifteen feet deep at the time it was seen by the writer. Two tills were distinctly exposed in the section, the relations of which are shown in Fig. 5.

The lower till, as in every case which has been described, is very homogeneous in composition. In this instance it is composed largely of the disintegrated material of a biotitic and hornblendic syenite, the source of which is probably close at hand. There is a slight admixture of foreign material but probably not more than 5 per cent. As in the case of the Ames

Pond exposure the till appears to have been originally composed largely of bowlders, the decay of which was well under way at the time of the laying down of the till, but which did not completely disintegrate until some time afterwards. Some of the larger bowlders still show undecomposed cores, but as a rule the disintegration is complete. The color is rather a dark brown, somewhat similar to the reddish-brown color of decomposed diabase, and serves to sharply separate the lower from the upper till.



Vertical and horizontal scale: 1 in. = 30 ft.

FIG. 5.— Section showing the relations of the older and younger tills in the Pine street exposure, Stoughton. (Exposure 5 of Fig. 2.)

The upper till is of the ordinary heterogeneous type abounding in foreign fragments, many of them rather far-traveled. There is proportionally little of the dark syenite in the upper till, differing in this respect from the Pearl street and Ames Pond exposures in which the predominating material of both tills is the same. When present in the upper till the syenite is fresh.

In the case of the Center street and Intervale Park exposures of Brockton the reasons have been given for regarding the tills as probably representing the earliest of the Pleistocene advances. One of the most prominent of these reasons, namely, the position of the till upon deeply decayed and unglaciated rock surfaces, cannot be applied with certainty to the last three tills described, since the immediately underlying rock is not exposed and its condition is not known. The difference in the colors is also a noticeable feature, the granite and syenite tills showing nothing of the high colors which characterize the tills derived from the conglomerate. A study of granites decayed *in situ*, however, shows that high colors are not the necessary accompaniment of disintegration such as the granite of the tills has undergone. The same close dependence of composition upon the underlying or immediately adjacent rock, the same small percentage of foreign material, the same highly weathered

character, and the same distinct or even sharp division from the overlying tills, all seem to point to an origin similar, and probably contemporaneous with that of the Brockton tills. The deposition of the tills is believed to date from the time of earliest Pleistocene ice advance.

POSSIBLE INTERGLACIAL ROCK DISINTEGRATION

A further reason for considering the tills composed of highly oxidized or disintegrated material as representing the first ice invasion lies in the fact that the weathering is distinctly more advanced than in the exposures of what seems likely to prove to be examples of interglacial weathering. It has been seen that at the advent of the first ice sheet the rocks of the region were deeply decomposed as, for example, the conglomerate at Brockton. It is also known that where the conglomerate was so situated as to receive full benefit of the erosive action of the ice of the last advance the ledges are perfectly fresh. Between these two extremes there are numerous examples of a partial breaking up of the ledges by atmospheric agencies, and a partial disintegration. Such a case is illustrated in Fig. 6.

The moderate amount of decay exhibited by ledges of this class, as compared with ledges known to be pre-glacially decomposed, or with tills formed from such decomposed material, and the considerable amount which they show as compared with the freshly glaciated ledges of the last ice advance, seem to make a plausible case in favor of the view of interglacial weathering. In this case we have a rough measure of the time from the earliest of the Pleistocene ice advances to the present time, for both the field relations and weathered character show that the conditions mainly antedate the last of the ice invasions. The evidence of this weathering, if it be accepted as interglacial, is indicative of the great length of such time as compared with that which has elapsed since the final disappearance of the ice.

The preservation of these ledges evidently depended in many cases upon the character of the topography, but this is not always the case. The general explanation probably lies in the

fact that all of the occurrences noted lie in the southern belt, in which, with the exception of the hills and other prominences, the work of the ice of the last invasion was largely one of deposition.

FIG. 6.—View of disintegrated ledge of conglomerate, Intervale Park, Brockton. The weathering is supposed to be interglacial in age.

SUMMARY AND CONCLUSIONS

1. The Pleistocene ice sheet on its first advance found a somewhat deeply decayed rock surface, many remnants of which are now to be seen.

2. The erosive power of the first advance was not sufficient to entirely remove the products of decay, for tills evidently composed of such products have been found by the writer beneath the ordinary tills of the region. These have been described in this paper.

3. The older tills are probably the result of the re-working of

pre-glacially decomposed rock and its accompanying soil, rather than by the process of accretion, by which many of the later deposits of till, such as drumlins, etc., were built up.

4. The remnants of the early till are characterized by (*a*) the presence of 20 per cent. or more of clay, (*b*) the presence in some of the tills of 10 per cent. or less of pebbles, (*c*) a composition which is dependent almost entirely upon the underlying or immediately adjacent rock, (*d*) the decayed or disintegrated character of its materials, (*e*) the presence of colors characteristic of high oxidation, (*f*) its position in certain cases upon deeply altered and practically unglaciated rock surfaces, and (*g*) its distinct line of demarcation, both as to color and composition, from the overlying till.

5. The upper till, on the other hand, is characterized in the region under discussion by (*a*) the presence of probably less than 5 per cent. of clay, (*b*) the presence of 40 to 50 per cent. of rock fragments, (*c*) a composition often largely independent of the immediately underlying rock and including numerous far-traveling erratics, (*d*) slight oxidation, and (*e*) by its unweathered and distinctly glaciated fragments.

6. No evidences of a soil zone between the two tills have so far been observed.

7. It seems probable that there were comparatively few localities in which the highly oxidized tills remained at the time of the last invasion, for otherwise there should be more traces of oxidized material, especially the colored clays, in the later till. The early tills were probably largely eroded during the later stages of the same ice sheet by which they were formed.

8. The action of the ice of the last advance in many cases was to cover the earlier till remnants by a new coating of till, and was protective rather than erosive in its nature.

9. Nothing indicative of more than two general periods of glaciation has been noted by the writer. The position of stratified deposits between two tills identical in character, and of the Wisconsin type, is probably to be explained as resulting from

the overriding of deposits laid down during a temporary retreat or local recession of the ice of the same general invasion.

10. The post-glacial weathering is in general confined to a slight oxidation of the till, the wearing of the pebbles, bowlders, and glaciated ledges being usually limited to a slight superficial decay or a mere discoloration of the surface.

11. There are numerous exposures showing rock disintegration of a type intermediate between the high decay characteristic of the pre-Pleistocene weathering and the slight weathering of post-glacial times. This disintegration is believed to have taken place largely in interglacial times.

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SKETCH OF THE GEOLOGY OF THE SALINAS VALLEY, CALIFORNIA[1]

In June and July 1900, under the direction of Dr. J. C. Branner, Mr. L. D. Mills and the writer undertook to trace out and map the formations in Monterey county, California, which appear to bear directly on the underground water supply of the Salinas Valley. During this and two subsequent trips to the same region the data were collected which form the basis of the present paper.

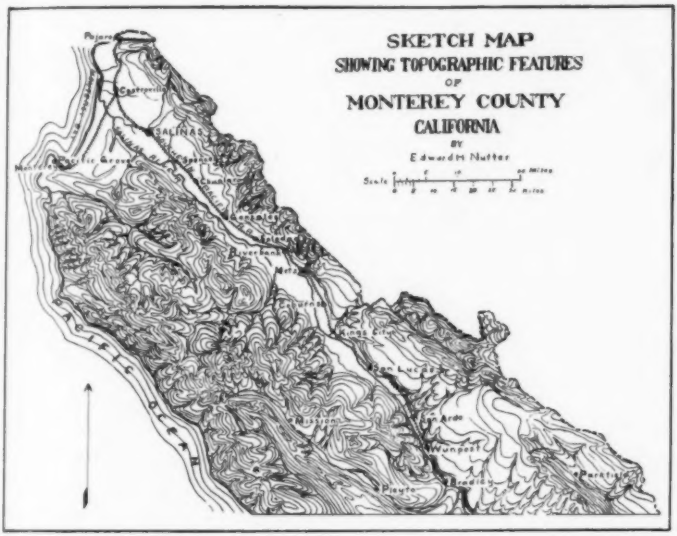
The Salinas Valley is a long, sword-shaped depression extending nearly southeast from Monterey Bay, to and across the southern end of Monterey county. The larger tributaries of the Salinas River run for a good part of their length in troughs parallel to the main valley, forming with it part of a remarkable series of valleys existing in the Coast Ranges of California, which for a distance of nearly five hundred miles are almost exactly parallel. In the Salinas Valley are evidences of a fault in the older rocks extending very persistently for several miles parallel to the main valley.

In its northern part, if not throughout its whole length, the Salinas Valley is cut in granite and other crystalline rocks, principal among which are biotite schists with crystalline limestone lying unconformably on them. The granite is intruded into the schists and is apparently the agent which metamorphosed the limestone. The granites, gneisses, and schists cover large areas while the limestone occurs only in patches. Of the crystalline rocks other than those mentioned there is one area of an eruptive that looks like andesite on top of the water-shed between Monterey and San Benito counties, northeast of the town of Salinas, and an area in the neighborhood of Metz containing a variety of intrusive and eruptive rocks in addition to several kinds of metamorphics. Hand specimens of these have been collected

[1] Published by permission of the director of the U. S. Geological Survey.

but have not yet been identified. There is also an extensive area of serpentine along the southeastern boundary of Monterey county.

Since it was cut out the Salinas Valley has been filled with sediments of Tertiary and later age. If there are sediments older than the Miocene and newer than the metamorphics, they

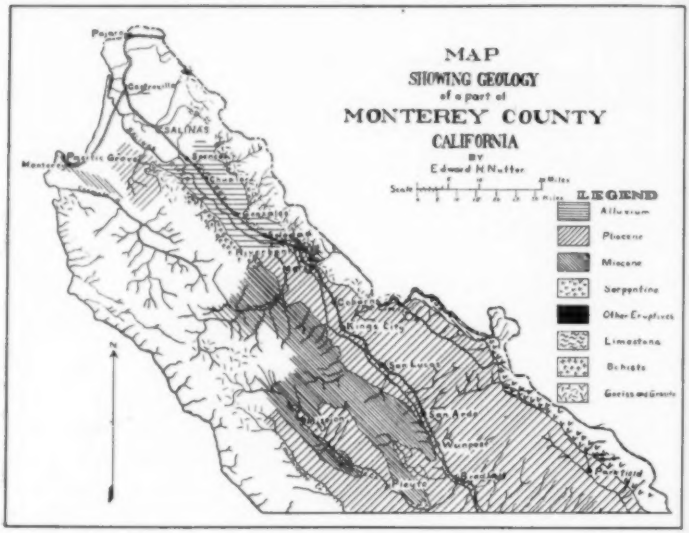


are not uncovered at any place visited, with the exception perhaps of a small area about the headwaters of the San Lorenzo River near the county line, where there are rocks resembling the Franciscan cherts. The Tertiary rocks are of Pliocene and Miocene ages, and these are separated by an unconformity.

Southeast from the town of Salinas the valley narrows down from a broad rolling plain to a sloping floor about eight miles wide, bounded on each side by granite mountains. Southwest of Salinas, across the river, are highlands formed of Pliocene[1] sands and gravels, and deeply scored by ravines.

[1] The age of these beds was determined by Mr. Ralph Arnold, of Stanford University, from fossils collected by the writer fourteen miles east of Monterey, in the center of section 20, 16 south, 3 east.

From Spence's to a few miles southeast of Soledad the floor of the valley is covered by material washed in from the granite hills and mountains on either side. This alluvium or granite wash is very porous, and this has given rise to topographic features characteristic to this part of the valley. In the rainy season the water rushes out of the steep canyons bearing a heavy burden



of sediments until it reaches the floor of the valley, where it sinks, leaving sand, gravel, mud and drift strewn around over the place where it disappeared. This has gone on until alluvial cones have been built up several miles wide and of considerable thickness. These alluvial cones or fans have themselves been cut by smaller gulches having steep sides and flat bottoms. A rudely stratified earthy conglomerate, the pebbles of which are angular fragments of granite, schist and gneiss, varying in size from sand grains to pieces the size of one's head, is usually found capping these fans.

It seems probable that both Pliocene and Miocene sediments underlie the alluvium, for they occur at the northwestern end of

this area and dip under it at the southeastern end below Soledad. In addition to this, there is a point of granite projecting through one of the alluvial fans about two and one half miles east of Gonzales in 16 south, 3 east, section 14, southeast quarter. The top of this granite exposure is capped with shale that has all the appearance of the diatomaceous Miocene shale. It seems probable that the structure of this region is that shown in the accompanying section (Fig. 1).

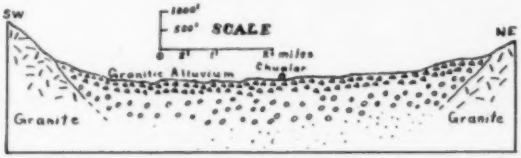


FIG. 1.—Ideal section across the Salinas Valley showing its probable structure at Chualar.

Beginning near Riverbank on the east, and at a point about six miles southwest of Soledad, on the west, water-worn gravels of Pliocene age begin to crop out from beneath the granitic talus, and gradually rise and form a terrace that extends eastward for about eighteen miles from Kings City to a series of anticlinal valleys which form the eastern boundary of the terrace or plateau.

Serpentine is abundant along the eastern edge of the terrace, though whether or not it forms a continuous sheet as indicated by the accompanying sketch map is not now known, for the part-

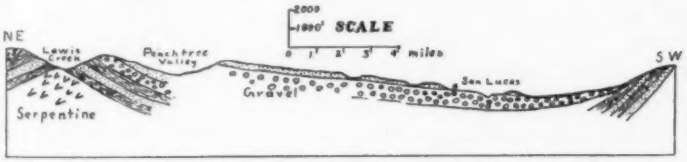


FIG. 2.—Structure of the Salinas Valley and adjoining plateau along a northeast-southwest line through San Lucas.

ing was not followed continuously, but was visited only at such places as the roads permitted. At these points serpentine was found underlying the Pliocene plateau. The edge of contact between the Pliocene beds and the underlying serpentines

reaches an elevation of nearly two thousand feet above Kings City from near Parkfield northwest to a point fifteen miles east of Kings City.

The structure of the country between Kings City and the alluvium covered district is shown by (Fig. 3) a section through Metz.

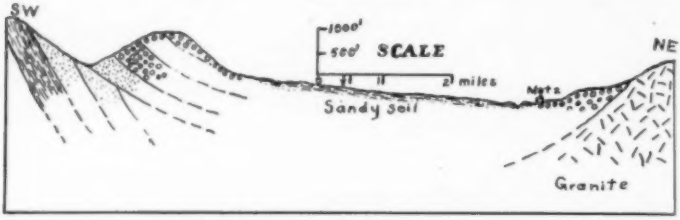


FIG. 3.—Structure of the Salinas Valley along a northeast-southwest line through Metz.

From Kings City to the San Luis Obispo county line the Pliocene beds form the eastern escarpment of the immediate valley with an average height of about one hundred feet above the river. The lower beds extend entirely under the valley, thereby making the terrace area or plateau tributary to its underground water supply.

For the most part the Pliocene beds overlie the Miocene, but in some places they lie directly on the older rocks (Fig. 4).

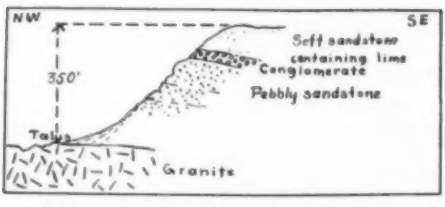


FIG. 4.—Croppings of terrace beds five miles northeast of Kings City at the head of the Salinas Valley Water Company's ditch, on the San Lorenzo River.

In the southern part of Monterey county there have been at least two elevations of the land since the deposition of the Miocene beds, for the Pliocene gravels forming the large plateau are to a great extent composed of shale pebbles, and these same pebble beds have been tilted along with the underlying beds of shale. In places the Pliocene and Miocene may be conformable.

This seemed to be the case near the southernmost point of the Miocene area shown on the accompanying geological sketch map. Here the gravels and sands rest on the sandstones and shales and have apparently the same dip and strike. For the most part, however, along the parting between the Pliocene and the Miocene, there is such a marked difference in the dip of the two series on either side of the contact, as to make almost certain an erosion line between them.

The Miocene shales and sandstones are much contorted, and

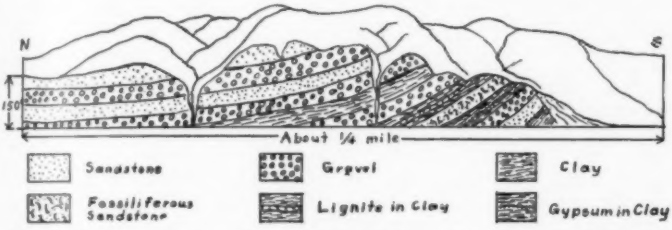


FIG. 5.—Terrace beds exposed in a railway cut three miles northwest of Bradley.

are characterized by steep dips, sometimes vertical. The Pliocene sands and gravels[1] have much gentler dips and are also persistently characterized by having a capping of soft limy sandstone.

The ranges of hills lying between the Nacimiento and San Antonio creeks, and the San Antonio Creek and the Salinas River are made up almost entirely of Miocene sandstones and shales; while the valleys of the Nacimiento and San Antonio are filled with the Pliocene sands and gravels.

There is much granite and gneiss in the region drained by the head waters of the Arroyo Seco, the San Antonio, and the Nacimiento, as the beds of these streams are filled with pebbles and bowlders made up of these rocks.

[1] The age of this Pliocene area was determined by fossils collected in a railway cut three miles northwest of Bradley. The Miocene fossils are from shale beds outcropping on the southwest bank of the Salinas River at Wunpost. They were all identified by Mr. Ralph Arnold.

RECAPITULATION

The Salinas Valley in Monterey county is a trough that probably holds a great deal of water. In its northern part from near Riverbank to some point between Chualar and Salinas it is covered with talus washed in from the mountains.

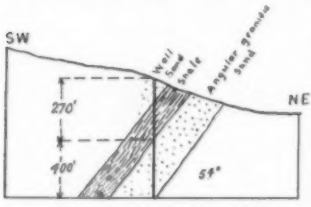


FIG. 6.—Sand and shale beds at Barrett's oil well, four miles northwest of Parkfield. Water was encountered at two levels in the angular granitic sand. The elevation of the mouth of the well is 1800 feet above Kings City.

Pliocene and Miocene sediments underlie this talus though to what extent is uncertain. Going southward the Pliocene beds rise from beneath the talus at about Riverbank; and from east of Kings City, to the southward, they form an extensive plateau which continues into San Luis Obispo county and is probably tributary to the underground water supply of the Salinas Valley.

In the drainage area of the San Antonio and Nacimiento creeks there are also Pliocene gravels which are indirectly tributary to the underground water supply of the Salinas Valley.

It seems probable that deep wells put down near the western margin of the Pliocene terrace between San Lucas and the San Luis Obispo county line may yield considerable water, perhaps artesian.

Slightly salty water has been found in wells in the terrace beds above the valley, though there are folds lying between these bore holes and the valley (Fig. 6).

It is possible that artesian water may be found in the region of the San Antonio and Nacimiento creeks, but not enough detailed work has been done there to warrant any definite conclusions upon the subject at present.

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NOTES ON THE FOSSILS FROM THE KANSAS-OKLAHOMA RED-BEDS

THE age of the series of rocks lying conformably on the Permian and unconformably below the Comanche Cretaceous in Kansas and Oklahoma has for a number of years been considered problematic. The earlier Kansas geologists classified these formations anywhere between the Carboniferous and the Middle Cretaceous. Later investigators have agreed that the series is not older than the Permian, nor more recent than the Jurassic. In Texas, rocks which appear to be of the same age are assigned to the Permian on the authority of such paleontologists as Cope and White.[1]

In the absence of certain determination as to age, the general term Red-beds has been applied to these formations in Kansas and Oklahoma. The term refers to the lithological appearance of the rocks. Blood red sandstones, clays, and shales make up the greater part of the thickness of the series. The shales are frequently strongly impregnated with mineral salts, of which gypsum and common salt form the larger part, although borax, magnesia, and others are not infrequent. These salts impart to the water of a great part of the area a characteristic taste, often rendering it unfit for use. In the central part of the Red-beds areas several ledges of massive gypsum occur. These ledges outcropping to the east form the escarpments and caps of the noted Gypsum hills which extend south from southern Kansas to the Wichita Mountains, and thence into central Texas. Ledges of dolomite and highly saliferous shales are found in many horizons of the Red-beds.

There is not lacking literature on the Red-beds. Some of the most noted geologists and paleontologists of America have written concerning these rocks. Such men as Cope, Hill, Williston, Haworth, Hay, Vaughan, Ward, Beede, Stevenson, and others

[1] Second Annual Report Geological Survey of Texas, 1890, pp. 415–419.

have contributed to our knowledge of the subject. The most comprehensive articles, however, are by Prosser and Cragin. Professor Cragin, in addition to incidental mention of the Red-beds in numerous papers on the geology of southern Kansas, has written two articles dealing exclusively with these series of rocks. In the first paper, entitled "The Permian Series in Kansas,"[1] the Red-beds are classified as Upper Permian, and are included under the Cimarron series, which is divided into two divisions, the Salt Fork and Kiger. Each of these divisions is further subdivided on purely lithological grounds into five formations. Professor Cragin's second paper, "Observations on the Cimarron Series,"[2] is little more than a revision of the former one. The grouping of formations and sub-formations is slightly changed, and a few new points added. These two papers contain the best description of the Red-beds extant. Professor Prosser's paper on "The Cimarron Series, or the Red-Beds,"[3] contains the best historical review of the literature of the subject so far published, as well as an excellent description of the Kansas Red-beds.

The reasons for assigning the Kansas-Oklahoma Red-beds to the Permian were chiefly two, viz., first, these rocks were considered to be of the same age as the Texas Red-beds, which are recognized as Permian; and, second, the series grades conformably upward from rocks of undoubted Permian age. The fact that so far as known not a single fossil has been found in the Kansas Red-beds has always been the great obstacle to the accurate correlation of the series. During the past two years, however, as the result of both private investigation and of the work of the Oklahoma geological survey at least four localities have been discovered in the Oklahoma Red-beds from which fossils have been identified. These localities, with the character of the fossils contained in them, are as follows:

1. McCann's quarry, five miles southeast of Nardin, Kay county; vertebrates, invertebrates, and leaves.

[1] Colorado College Studies, March 1896, Vol. VI, pp. 1–48.

[2] American Geologist, May 1897, Vol. XIX, No. 5, pp. 351–363.

[3] University Geological Survey of Kansas, 1897, Vol. II, pp. 75–95.

2. Two miles northeast of Orlando, numerous vertebrates.

3. Cedar Hill and Bitter Creek, northeast of Watonga; invertebrates.

4. Whitehorse Spring, sixteen miles west of Alva; numerous invertebrates.

Of these localities those numbered 1 and 2 are from the lower part of the Red-beds, not far from the base of the Harper sandstone. The fossils from locality numbered 3 were taken from ledges of sandy dolomite immediately beneath the heavy ledges of gypsum found near the middle of the Red-beds. Locality numbered 4 is from the Red Bluff sandstone in the upper part of the series.

A large vertebrate from McCann's quarry, or locality 1, was identified by Dr. S. W. Williston as *Eryops megacephalous* Cope, a form characteristic of the Permian of Texas. The invertebrates from the same locality were sent to T. Rupert Jones, who classified them as *Estheria minuta*, a Triassic form. The plants were shown to Dr. Lester F. Ward, who said that the forms seemed to resemble Mesozoic rather than Paleozoic types. From the Orlando locality Dr. Williston has identified the following forms: *Diplocaulus magnicornis* Cope; *Diadectidæ* Gen. indt.; *Pariotichus incisivorus* (?) Cope; *Labyrinthodont;* and *Trimerorhachis;* all of which he recognizes as Permian forms. From the locality numbered 3 but one species has been found. This is an invertebrate which here occurs in great numbers, and has been referred by Dr. J. W. Beede with some doubt to the Permian form *Sedgwickia*. The Whitehorse locality has yielded some twenty species of invertebrates, several of which are of new forms.

This locality is from the upper part of the Red-beds, or to be more exact from Cragin's Red Bluff sandstone perhaps 150 feet above the Medicine Lodge gypsum. The following genera are represented: *Conocardium*, *Aviculopecten*, *Schizodus*, *Pleurophorus*, *Bakevalia*, *Naticipsis*, *Pleurotomaria*, *Orthonema* and *Murchisonia*. One form that was at first thought to be *Jagmayeria*, a shell of Triassic age, has since been identified as *Dielasma*, very

like *D. biplex* described by Waagen from the Permo-Carboniferous of India.

Unfortunately no Cephalapods have as yet been found in the locality and until this is done the question of the exact age of the beds may scarcely be decided. The facts at command lead to the inference that the Whitehorse Springs locality is well up toward the close of the Paleozoic

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ILLUSTRATED NOTE ON A MINIATURE OVERTHRUST FAULT AND ANTICLINE

THE figure below represents a miniature anticline passing into a reversed fault above. It is on the Ozark-St. Paul road, on the east side of the road, one mile north of the town of Ozark, Ark. The rocks are of the Coal-measure series, and consist of shale interbedded with thin layers of sandstone. The strike of the fold is about east and west, it being one of the series of feeble folds on the northern border of the Ouachita folded area and near the southern base of the Boston Mountains.

The length of that part of the flexure which is visible, and which at the time the photograph was taken had recently been freshly exposed in working the road, is ten feet, and the height five feet.

Aside from the interest which attaches to this as an example

of an overthrust fault passing into an anticline below, it bears strong evidence of very recent tangential pressure having been brought to bear upon the rocks of the region; for it is inconceivable that so small a flexure should break and produce a fault with many feet of superimposed rock to be broken through. The point is sufficiently elevated to suffer from slight erosion, and as the rock is mainly shale and easily eroded, the very few feet that have been removed since the faulting occurred could not represent much time, as the geologist reckons time.

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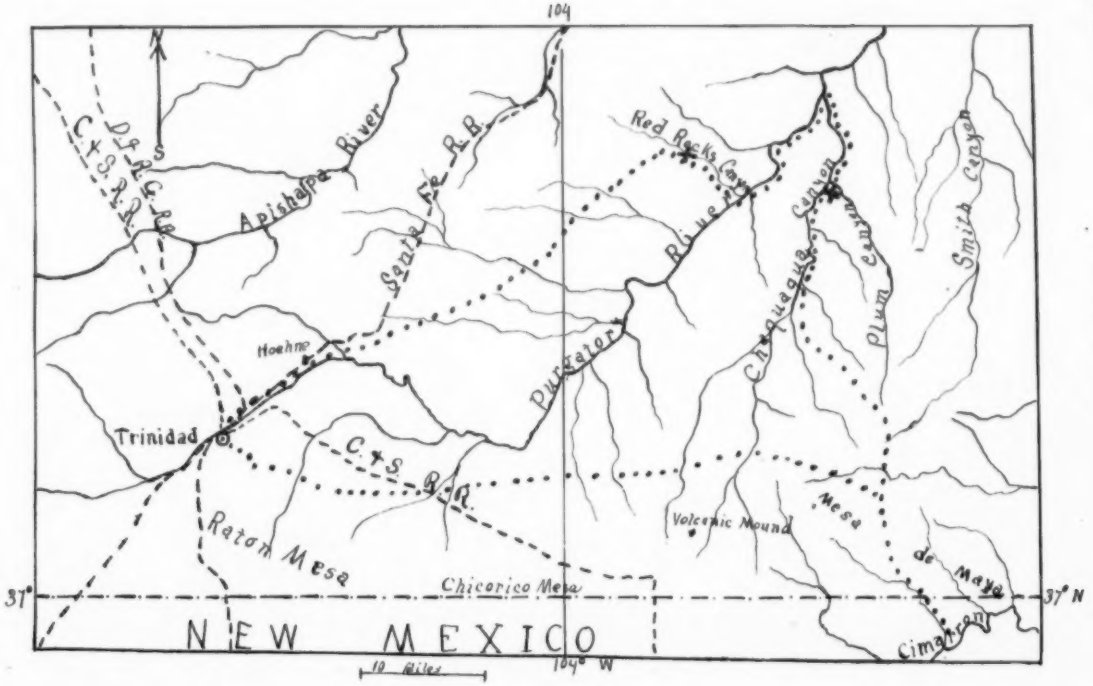
THE MORRISON FORMATION OF SOUTHEASTERN COLORADO

A CONSIDERABLE part of southeastern Colorado and northeastern New Mexico is elevated to a height of about 5000 feet above sea level. The streams of this region have cut canyons to the depth of 700 feet or more. The most notable of these is the canyon of the Cimarron in New Mexico, and that of the Purgatory, or Las Animas, in Colorado. The studies of which the conclusions are given in this paper, were carried on mainly in the canyon of the Purgatory and its tributaries, although a side trip was made to the canyon of the Cimarron. The region examined is shown in the accompanying sketch map (Fig. 1). The canyon walls are steep and bare and complete sections are easily obtainable. The lower half is red sandstone overlain with gypsum (the "Red Beds"); the surface rock is also sandstone (Dakota.) Between this upper sandstone and the gypsum is the shale formation of which I specially write. The shales are found throughout the region examined wherever the streams have cut through the upper sandstone.

Two detailed sections were taken at the points indicated on the map by a cross (×), section 1, at the junction of Plum and Chaquaqua canyons, and section 2, in Red Rocks Canyon. Since the canyons do not cut entirely through the Red Beds at any point within the area examined, it is impossible to accurately estimate their full thickness; the sections, therefore, represent only the upper part of these beds.

For some distance above the bottom of Plum Canyon (section 1) the rock is evenly stratified, ripple-marked and somewhat shaly. A limestone layer four feet thick near the bottom extends uninterruptedly for many miles and forms a convenient line of reference. Above these evenly stratified beds occurs a series of massive layers of coarse red sandstone aggregating about 250 feet in thickness. This series forms the steepest and

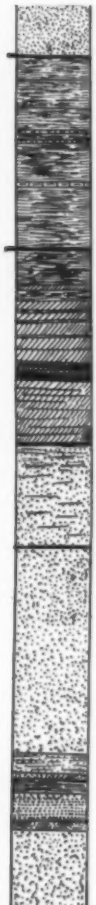

104
Red Rocks Cave
Apishapa River
Santa Fe R.R.
Hoehne
Trinidad
Purgatoire
Chaquaqua Canyon
Plum Canyon
Smith Canyon
Volcanic Mound
Mesa de Maya
Raton Mesa
Chicorico Mesa
37°
37° N
NEW MEXICO
104° W
10 Miles

most conspicuous part of the canyon walls. It is notably cross-bedded and the frequent changes in the direction of bedding, as well as the frequent truncations of the cross-bedded layers, is indicative of deposition by shifting currents. The upper part of the massive series is slightly calcareous and oölitic, the little spheres of which, about one millimeter in diameter, are harder than the matrix in which they are set, and the weathered surface is thus given a "bird's-eye" appearance. The oölitic beds pass gradually upward into gypsiferous shales and thence into solid gypsum without any indication of stratigraphic break or lapse of time. No trace of fossils of any kind was found in the Red Beds.

The upper sandstone forms the general surface of the country over wide areas. The Cretaceous formations from the Ft. Pierre to the Dakota are traversed in passing eastward from Trinidad across the El Moro quadrangle which has been described by R. C. Hills,[1] and the Dakota, may be traced onward thence over the whole region studied. The Dakota is composed mainly of sandstones, although shales occur in it in places. About 150 feet from the base occurs a steel-blue shale (probably fire-clay), 2 to 6 feet thick were examined. Above this clay the formation is somewhat evenly bedded, ripple-marked and in certain places contains numerous impressions of dicotyledonous leaves. In a few places small pebbles were found near the base. The largest of these were about one fourth inch in diameter. The pebbles are so few in number that the strata containing them can scarcely be described as conglomeratic.

Between the Dakota and the gypsum at the top of the Red Beds lies the shale formation under consideration. It is constant in occurrence, although the thickness varies from place to place. At the mouth of Plum Canyon the thickness is 85 feet; in Red Rocks Canyon, it is 132 feet. In Chaquaqua Canyon, ten miles from the mouth of Plum Canyon, it is 175 feet (by barometer). The formation is composed mainly of variegated clay-shales of the variety known as "joint clay." A subordinate amount of

[1] U. S. Geol. Surv., El Moro Folio, Colo.



140 feet. Dakota. Two massive sandstone layers separated by a soft shaly layer of varying thickness; leaf impressions near the top of the upper division.

11 feet Greenwich clay shale, soft and fine grained.

12 feet dull red clay shale, soft and fine grained.

10 feet brown to yellow shale.
6 inches argillaceous limestone; numerous fine dark laminæ.
18 inches buff-colored shale.
6 inches argillaceous limestone; numerous fine dark laminæ.

18 feet variegated joint clay.

2 feet argillaceous limestone, fine grained and hard, with contorted laminæ.

30 feet variegated shales; very soft and easily eroded.

15 feet dark shales containing irregular masses of gypsum.

18 inches gypsum containing streaks of clay.
8 feet variegated shale containing nodular-like masses of gypsum which vary in size from grains to masses a foot or more in diameter. About one third of the mass is gypsum.

25 feet gypsum in well-defined layers. Often separated by layers of clay.

5 feet massive gypsum.

30 to 40 feet red gypsiferous shales, soft and regularly bedded.

60 feet red calcareous sandstone, oölitic, cross-bedded. Individual layers variable in thickness and character. Near the top it becomes shaly and passes gradually into the gypsiferous shales above.

175 to 200 feet red sandstone, massive, cross-bedded.

6 feet red arenaceous shale.
1 foot red sandstone.
4 feet fine red shale.
9 feet even-bedded red sandstone.
2 feet red arenaceous shale.

40 feet red sandstone, cross-bedded; the individual layers thin out laterally.

15 feet poorly cemented red sandstone alternating with layers of shale.

5 feet massive red sandstone.

30 feet soft red sandstone containing hard layers which are ripple-marked.

4 feet hard, white, argillaceous limestone composed of numerous thin layers; greatly contorted.

15 feet red sandstone in thin flaky layers.

(River bottom.)

FIG. 2.—Section 1, near the mouth of Plum Canyon.

Dakota sandstone.

25 feet brick-red arenaceous shale, containing bands of hard, fine-grained sandstone.

3 to 5 feet reddish limestone having a conchoidal fracture and very brittle.

30 feet soft dark clay shale.

11 feet light brown clay shale.
6 inches argillaceous limestone.
7 feet brown shale.
1 foot concretionary limestone.
7 feet variegated clay shale; joint structure.
3 feet fine yellow paper shale.
6 inches argillaceous limestone, finely laminated.
18 inches fine shale.
1 foot white limestone.
15 feet variegated clay shale.
8 inches argillaceous limestone, finely laminated.
4 feet yellow shale.
1 foot sandstone containing agate either in concretionary masses half an inch or more in diameter or disseminated generally throughout the mass.
8 feet sandstone, easily crumbling; made up of thin layers.
2 feet massive sandstone, poorly indurated.
2 feet fine paper-shale.
7 feet massive sandstone, poorly indurated.

12 to 20 feet gypsum interstratified with layers of clay.

— red sandstone (Red Beds).

FIG. 3.—Section 2, in Red Rocks Canyon.

sandstone occurs in places but there seems to be no particular horizon at which this is likely to be found. In Red Rocks Canyon it occurs at the base; in Plum Canyon, none is found; in a side gulch east of Plum Canyon a brecciated layer occurs near the top containing angular fragments one quarter inch in diameter; in Chaquaqua Canyon, four miles from the mouth of Plum Creek, a coarse cross-bedded sandstone layer 15 feet in thickness occurs about 50 feet from the top; just across the canyon from this point, perhaps two miles distant, and at the same horizon, about 30 feet of limestone is found in place of the sandstone. In many places the sandstones are friable and composed of nearly pure quartz. The sand is used as a flux in assaying where pure silica is required. The occurrence of the limestones, most of which are more or less argillaceous, is as eratic as that

of the sandstones. The relative amount and position of sandstones, shale and limestones at any one point is no indication that a similar relation will be found at any other point. There is no abrupt lateral change, but the various beds blend into each other or pinch out laterally in a gradual though somewhat rapid manner, so that, while no sudden change is seen, a comparison of sections a few miles apart may show a total change in kind and relation of materials. The Dinosaur bones to be described later were found in the shales at nearly every horizon. Aside from these, no fossils were found. Careful search at every horizon failed to reveal a single invertebrate.

The three formations—the Red Beds, the shales, and the Dakota sandstone—are apparently conformable. There seems, however, to be some indication of a break between the gypsum and the shales, and still more between the shales and the Dakota sandstone. The red sandstone, as already pointed out, passes upward through shales into the gypsum by a gradual transition. There was no evidence found, at any of the places examined in detail, of a break in deposition between the red rocks and the gypsum. At the top of the gypsum the evidence is not so satisfactory in every case. In Red Rocks Canyon the change is abrupt from gypsum to sandstone; but in Plum Canyon and elsewhere the upper layer of the gypsum beds is shale containing irregular masses of gypsum. This is overlain by the variegated shales. The gypsum beds vary in thickness from 20 to something like 100 feet. In some places, at least, as shown in the sections given in this paper, the shales increase in thickness as the gypsum decreases, and vice versa. It is possible, therefore, that the gypsum beds were exposed and slightly eroded previous to the deposition of the shales. However this may be, it seems clear that the gypsum belongs to the Red Beds series, and probably marks the closing stage of the Red Beds period. If this interpretation be correct, there is no gypsum in any part of the shale formation of southeastern Colorado, so far as known. The contact of the shales with the Dakota sandstone is more plainly marked, and in places exhibits gentle undulations,

which appear to be due to erosion of the shales previous to the deposition of the Dakota.

Vertebrate fossils were found in the shales near the mouth of Plum Canyon in a number of places. No means were at hand for digging deep enough to obtain good material, but many fragments were found on and near the surface. Two of the best preserved fragments—the centrum of a vertebra and the portion

FIG. 4.

of a femur—are shown in the photograph, Fig. 4, about one eighth natural size. The dimensions of the vertebra are as follows:

Length	8	inches
Transverse diameter at ends	7	"
Depth at ends	8	"
Transverse diameter at center	5¼	"
Depth at center	6½	"
Depth of sockets, each	½	"

The fragment of the femur is 13 inches long, 12 inches wide, and 7 inches in diameter. This does not represent the thickness of the complete bone, since one side is imperfect. These bones are solid and coarse in texture. One hollow bone was also found. The piece is about 5 inches in diameter and 7 inches long, with a hollow 2 inches in diameter. The material obtained is not sufficient for generic determination, but in size, texture,

and general aspect the bones are similar to the Dinosaurian remains of the Atlantosaurus Beds of central Colorado and Wyoming.[1]

That portion of the general section for the Rocky Mountain region which is useful for present comparison is as follows: The Red Beds formation (the so-called Jura-Trias) is overlain by the Morrison formation, or Atlantosaurus Beds. The line of demarcation is drawn at the top of the gypsum beds which occur in several localities along the mountains at the summit of the Red Beds. The gypsum is regarded as marking the closing stage of the Red Beds period. The Morrison formation, which averages about 200 feet in thickness, is composed principally of variegated shales. These contain sandstones and impure limestones, the thickness and relative position of which vary from place to place, or may be entirely wanting. It is this formation which is noted for its huge Dinosaurs. Above the Morrison occurs the Dakota sandstone. It should be borne in mind that only the middle one of these three formations, the Morrison, contains Dinosaurian remains.

Since the vertebrate fossils of southeastern Colorado have not been studied, and since they are the only known fossils from the shale formation of that region, we must resort to other means of determining the age of the shales, and these will be chiefly stratigraphical and lithological, to which may be added such general paleontological evidence as may be drawn from unidentified bones.

a. As stated in a previous paragraph, the upper sandstone of the region in question was traced from a known area, and there can be little doubt, therefore, that it is Dakota. The Red Beds are in structure, color, and general aspect similar to the Red Beds of the mountain region, seventy-five miles to the west. They differ only in being composed of finer material and in being massive near the top instead of evenly stratified, as is often the

[1] Since writing this article my companion, Mr. T. A. Pierce, has again visited the bone beds and found a number of new localities where bones occur in considerable numbers. The width of the territory in which these remains are found and their number indicate that this region would yield rich rewards to the bone hunter.

case in the typical Red Beds along the mountains. The stratigraphic position of the shale formation is between the Dakota and the Red Beds. In this respect its position is identical with that of the Morrison.

b. In lithological character, the shale closely resembles the Morrison, which, in its typical areas[1], is composed of soft, variegated clay, containing more or less sandstone and limestone. A comparison of the shale formation with the typical Morrison of Colorado shows a striking resemblance. There is a somewhat greater proportion of clay than in the Morrison, as would naturally be expected so far from the mountain area, which was probably a part of the feeding ground at that time. A comparison of the Morrison (Como) of Wyoming reveals a still closer resemblance, if, indeed, it cannot be called identity. One who is familiar with the Morrison and has studied the shales of southeastern Colorado finds a striking likeness between the two in material structure and general aspect.

c. The Morrison is notable chiefly for the great Dinosaurs found in its beds, and they are not found in the Dakota above nor in the Red Beds beneath. The bones found in the shales near Plum Canyon are similar in size, texture, and general aspect to the characteristic Dinosaurs of the Morrison formation. Although none of these bones have yet been studied by a paleontologist, there is little doubt that they are Dinosaur bones, and if Dinosaurs occur between the Dakota and the Red Beds, the presumption is that the formation containing them is an equivalent of the Morrison.

The shales found in the Canyon of the Cimarron perhaps deserve separate discussion. Near the southern boundary of Colorado is the divide between the Cimarron and Purgatory rivers. On this divide, a distance of nearly thirty miles, no stream, so far as observed, cuts through the Dakota. At the top of this divide is an extensive mesa capped by flows of basalt and

[1]See U. S. Geol. Surv., Monograph XXVII, Geology of the Denver Basin, p. 52; also W. N. LOGAN, Kas. Univ. Quarterly, 1900—"The Stratigraphy and Invertebrate Faunas of the Jurassic Formation in the Freeze-Out Hills of Wyoming," pp. 113-115.

known as Mesa de Maya. It is a part of the volcanic region extending from the mountains eastward along the southern border of Colorado. This mesa is separated from the equally elevated region of northern New Mexico by the canyon of the Cimarron, which is cut not only through the basalt and the Dakota, but deep into the Red Beds. Here, as further north, a shale formation lies between the Red Beds and the Dakota. At the one point studied gypsum occurs near the top of the Red Beds, but a thick stratum of red sandstone lies between it and the overlying shales. The shales correspond closely in character and general appearance with those further north, although they are more arenaceous and thicker (about 350 feet). No fossils of any kind were found, but enough was seen of the formation to warrant the inference that it is probably the same as the formation which occurs in the same position in the canyon of the Purgatory, thirty miles further north, viz., the Morrison.

SUMMARY

1. From the foregoing considerations it appears that the stratigraphic, lithologic, and paleontologic evidence all point to the inference that the shales of southeastern Colorado are of Morrison age. It is inferred, furthermore, that this formation extends from its line of outcrop along the flank of the Front Range, underneath the Dakota, as far east as Smith Canyon, about seventy-five miles, and as far south as the canyon of the Cimarron. How much further it extends in these directions is not determined.

2. Although there are gypsiferous shales lying between the gypsum and the fossiliferous shales, which might seem at first thought to form a transition, it is thought that the line of demarcation should be drawn at the top of the gypsiferous shales. If this division be correct, there is no gypsum in the Morrison formation of southeastern Colorado. In this it differs from that formation as reported from some localities. The gypsum is here considered as belonging to the closing stage of the Red Beds period.

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TRINIDAD, COLO.

Editorial

The Journal has had occasion to comment with some severity on the action of certain former officials of the state of Missouri relative to the official geological investigations of that state. It is therefore with the greatest pleasure that it now makes note of the recent appointment of a new Board of Managers of the Bureau of Geology and Mines, by Governor A. M. Dockery. The following gentlemen have been elected officers of the Board: President, Professor E. M. Shepard, Springfield, Mo.; Vice President, Dr. E. B. Craighead; Secretary, Colonel H. H. Gregg, Joplin, Mo.; Dr. W. S. Allee, Olean, Mo. The headquarters of the survey have been removed to the School of Mines at Rolla, under orders from the legislature. A state geologist will soon be appointed.

Reviews.

Department of Geology and Natural Resources of Indiana, Twenty-fifth Annual Report. By W. S. Blatchley, State Geologist, Indianapolis, Ind., 1900. Pp. 782. Maps and plates.

The current report deals mainly with the cement resources of the state. It opens with a short paper by the state geologist on Portland cement, a compilation treating of its history, uses, composition, process of manufacture, methods of testing, etc., together with a short history of the development of the industry in Indiana.

The report on the Lakes and Marl Deposits of Northern Indiana is the result of the joint work of the state geologist and and Dr. George H. Ashley. It is a thorough report of some three hundred pages and is accompanied by seventy maps of individual lakes on which the marl deposits in their varying conditions of occurrence are represented by conventional signs. In the body of the text, full physiographic descriptions of the lakes are given, as well as the detailed economic geology of the marl deposits. The notes on the natural history of these lakes, which are appended to the descriptions, are of much interest to the student of botanical ecology.

It is found that a deposit of marl of a thickness of ten feet and covering 160 acres will supply a factory of 500 barrels daily capacity for 30 years. Such a supply is termed a "workable deposit" in the report. There are thirty-two lakes which have at least that much marl available. With improved methods of raising marl from deeper waters, the productive area of these lakes will be much enlarged, and there will be added to the number half as many more, whose deposits are for the most part under water of greater depth than ten feet, the present limit of accessibility.

In regard to the origin of the marl the authors do not attribute more than 1 per cent. to shells as a source. The immediate source they believe to lie in the calcareous matter of the glacial clays which reaches the lakes in the form of the soluble double carbonate, $CaH_2(CO_3)_2$. This is believed to be carried by subterranean rather than superficial streams, because the marl deposits are found in

association with sub-lacustrine springs, while the mouths of streams and the currents leading away from them are marked by deposits of muck and silt. Calcium carbonate ($CaCO_3$) will be deposited if by any means CO_2 be withdrawn from the double carbonate. The authors recognize three such means.

1. Increase in temperature from mingling with the warmer lake waters.

2. Decrease in pressure as the spring water rises to the surface.

3. Extraction by aquatic plants, such as stoneworts, etc.

Since more than half the marl lakes do not have the stoneworts in abundance, and since the marl in general does not show that large percentage of organic matter which is shown by marls deposited through the agency of the stoneworts, the authors are inclined to minimize the part of aquatic plants.

As the spring water is colder than the lake water and denser owing to the carbonate in solution, we can see no cause for the rise of the spring water, except diffusion, in which the CO_2 released by ascending waters would be just balanced by that taken into solution by the descending currents.

If the main dependence is to be put upon the first means for removing the CO_2, *i. e.*, increase of temperature, it seems to us that springs which emerge superficially in the neighborhood of the marl lakes would have their waters warmed more rapidly than sub-lacustrine springs, and should thus have copious deposits of marl. No reference is made to such deposits. We believe a competent theory for the deposition of the marls is yet to be found.

The state is to be congratulated on the timely appearance of this report and will reap the benefits which accrue from early occupation of the field.

"The paper on the 'Silver Creek Hydraulic Limestone,' by Mr. C. E. Siebenthal, contains full details regarding the location and stratigraphy of the stone so largely used in southern Indiana for the manufacture of natural rock cement, as well as an historic, descriptive, and statistical account of the industry. It is accompanied by a map showing the exact location of the cement rock."

Of the Bedford limestone[1] there was quarried in 1900 some 7,035,000 cubic feet, with a value of $1,699,649.

[1] The article on this subject contributed to the current report by the writer, was made to read "Indiana Oolitic Limestone," without the consent or knowledge of the author.

From the report of the state mine inspector we learn that the production of coal in 1900 reached the largest figure in the history of the state, being 6,351,976 tons, valued at $4,883,024.18.

In a paper on the petroleum industry, the state geologist supplements his articles in the Twenty-first and Twenty-second reports, by noting recent developments in the main Indiana field, as well as in several smaller fields recently exploited. The paper is accompanied by a map of the field. The oil and gas reservoirs of the state are found to be mainly in the porous dolomitic upper portion of the Trenton limestone which does not appear at the surface anywhere in the state. The author conceives the dolomitization to have resulted from the concentration of sea water in the shallow indentations of the coast or marginal lakes, with resulting substitution of magnesium for calcium in the rock below. The total production of oil in 1900 was over 5,000,000 barrels, valued at about $5,000,000, one dollar per barrel.

The last paper in the report is from the pen of Dr. E. M. Kindle, and is entitled, the "Devonian Fossils and Stratigraphy of Indiana." It is one of the most important contributions which has ever been made to the knowledge of the paleontology of the state, and, with the exception of Dr. Foerste's work on the Silurian, is the only attempt which has been made to systematically explore the faunas of a group of Indiana rocks.

The first part of the paper takes up in detail the stratigraphy of the various localities, and discusses their faunal relations and correlation. The discovery at Delphi, Ind., of a new fauna in the New Albany shale leads Dr. Kindle to regard that formation as the western equivalent of both the Portage and Chemung, instead of the latter alone. Another interesting fact is that the Devonian limestones, which are well differentiated into the Sellersburg beds and the Jeffersonville limestone in the southern part of the state, give way to the dolomitic Geneva limestone and the Pendleton sandstone in the middle area, but resume their double facies again in the Wabash region, noting, however, that the Sellersburg beds hold very different faunas in the two regions.

The second part of the paper deals with the paleontology of the Devonian beds. The specific descriptions are preceded by keys for the discrimination of the species attributed to each genus, and these, taken in connection with the thirty-one excellent plates, comprising more than three hundred figures, make the paper an exceedingly useful handbook of this formation, particularly for Indiana students.

C. E. SIEBENTHAL.

Summary Report of the Geological Survey Department [of Canada] *for the Year 1900.* Ottawa, 1901.

Among the more interesting features of the work of the year are (1) a series of experiments in separating the magnetic element from black auriferous sands by a magnetic separator, and thereby concentrating the gold in the non-magnetic residues (collected by J. C. Gwillim, treated by J. B. Porter); (2) the discovery of salt at St. Grégoire in a red formation referred to the Medina, which throws light on the conditions attending the origin of that formation in common with other red sand and marl deposits; (3) a survey by J. McAvoy of the Crows Nest coal field, which is estimated to contain over 22,000,000,000 tons of workable coal of excellent coking qualities and low percentage of ash or other deleterious substances; (4) additional discoveries of Cretaceous coal in northern British Columbia, indicating that "the coal-bearing Cretaceous rocks occupy a much larger area than had been supposed between the 55th and 57th parallels of latitude, while anthracite coals have actually been found in the region about the head-waters of the Skeena and Stikine rivers" (J. S. O'Dwyer and A. H. Dupont); (5) a further report on the Klondike district, dealing with its indurated series and its gravels, gold and copper deposits, lignites, and glaciation (R. G. McConnell); (6) the exploration by J. C. Gwillim, of the Atlin district (about 60° lat. and 134° long.); (7) additional results in the Kootenay district; (8) an outline of explorations, by J. M. Bell, about Great Bear Lake and Great Slave Lake; (9) a brief statement of work on the crystalline area northwest of Lake Superior, by William McInnes; (10) a report of work north of Lake Superior, by Robert Bell, relating especially to iron ore developments; (11) studies, by W. A. Parks, in the Muskoka district; (12) examination of the region south and east of Ottawa, by Dr. Ells; (13) studies in the vicinity of Montreal, by O. E. LeRoy; (14) the examination of Shefford Mountain, by J. A. Dresser; (15) work in the Lake St. John district, by G. A. Young; (16) work on the great slate belt of New Brunswick, by L. W. Bailey, in which fossils indicating Ordovician and Cambrian ages were found; (17) investigations on the surface geology of northwestern New Brunswick, by R. Chalmers; (18) work in Nova Scotia on the coal field, by H. Fletcher and M. H. McLeod, and on the gold field by Mr. E. R. Faribault; (19) outlines of chemical, paleontological, and natural history investigations.

The preliminary determination of the geologic series of the Atlin district is as follows:

1. Sandstones and argillites of probable Cretaceous age, in the basins of southern Taku arm and Atlin Lake, with an expected continuation to the southeast by Pike Lake, and the Nakina River.

2. The characteristic rocks of Pine Creek basin are different varieties of magnesian combinations, together with some greenstones of a diabasic character. Magnesite, serpentine, dunite, greenstone, actinolite slates and a very friable gray limestone are the chief rocks. These were not seen outside of the Pine Creek and McKee Creek basins excepting in two or three localities. They extend in patches across Atlin Lake westward into Taku inlet and possibly over towards Taku arm to a point five miles south of Toochi River. Another area of these typical rocks is found about Chehalis Creek, south of Gladys Lake, as mentioned previously.

3. Cherty quartzites and various kinds of clay-slates, together with patches of gray or black limestone distributed over the great flats west of Dawson Peaks and Gladys Lake, O'Donnel River basin, and eastwards to Teslin Lake at its southern end.

4. Great masses of crystalline limestones on northern Taku arm, Little Atlin Lake, Lower O'Donnel River, and at the junction of Silver Salmon and Nakina Rivers.

5. Late eruptive rocks of basaltic and porphyritic characters, all about the southern parts of Atlin Lake, constituting the central portions of most of the groups of mountains there.

6. Granites of the Coast Range at the south end of Taku arm, and isolated masses of granite from the northern end of Atlin Lake eastwards across Surprise Lake, and Snowdon Mountains to near Teslin Lake; also McMaster Mountains east of Lower O'Donnel River, and the bowlder-stream plateaus seventeen miles eastward, from Ruth Lake on the Taku trail.

The conclusions relating to the ages of the rocks in the Kootenay district are as follows:

The crystalline gneisses and schists are of uncertain age, probably they include rocks of different age, but they are, at all events, among the oldest rocks of the district. The Nisconlith rocks are Lower Paleozoic, supposed to be about Cambrian. The Cache Creek rocks are Upper Paleozoic, probably Carboniferous. This is the age also assigned to most of the greenstones (andesites, porphyrites, serpentines, etc.), and the limestones and argilites associated with them. Some of the andesite and agglomeratic rocks in the Trail Creek district are no doubt younger, but there is no definite information regarding their age except that they are older than the conglomerates and the Rossland granite. The gray granite which cuts the greenstones is probably

about Jurassic. The monzonite-like rocks appear to be younger than the gray granite, which would indicate that they belong to the Cretaceous.

The conglomerates are amongst the younger rocks. The Lake Mountain conglomerate is supposed by Mr. McConnell to be Tertiary. It bears a strong resemblance, both lithologically and stratigraphically, to the conglomerates associated with the Tertiary volcanics on the Kettle River, which are supposed to be of Tertiary age. The Rossland granite, which sends dykes through the conglomerates both on Sophie Mountain and on the Kettle River, is evidently younger than these. Dr. Dawson has observed granite very much like the Rossland granite, cutting the Cretaceous rocks, in the Kamloops district. The Rossland granite, again, is newer than some of the basalts, as inclusions of the latter were found in it, and reddish porphyry dykes, seemingly identical with those from this granite, were observed cutting the lower volcanic beds. There seems good ground, therefore, for supposing this granite and the accompanying porphyries to be Tertiary (R. W. Brock).

C.

Aus den Hochregionen des Kaukasus. Wanderungen Eslebnisse, Beobachtungen von GOTTFRIED MERZBACHER. Two volumes, 1920 pages, 246 illustrations from photographs, 3 maps. Leipzig: Duncker & Humblot, 1901. Price, 40 marks.

This is another great work on the Caucasus, which may be compared favorably with that by Freshfield. The two large volumes by Merzbacher deserve a more extended review than it is possible to give them at this time. They present in very attractive form the result of much labor in exploring the peaks and snowfields, the glaciers and valleys of the lofty Caucasus, as well as in study and observation of the country and its peoples. Much labor has also been bestowed upon the preparation of the book, which appears in the character of the 246 illustrations, most of which, from photographs taken by the author, have been redrawn with great success artistically, especially those by E. T. Compton. The three topographic maps of the region, on a scale of 1 : 140,000, furnish a great deal of valuable detail. A most convincing evidence of the care taken with the preparation of the book is the index of 117 double-columned pages. So also are the frequent bibliographic references.

The first chapters are devoted to the general discussion of the orography and structure of the high Caucasus; their glaciers, hydrography, passes, and subdivision into three groups, western, central, and

eastern. Then follows a comparison of these mountains with the Swiss Alps, in which the Caucasus is shown to excel in loftiness and grandeur of peaks and mountain masses, and in wildness and solitude. But the Swiss Alpine valleys surpass those of the Caucasus in the charm of their beauty and restfulness. There are chapters on the ethnology of the peoples inhabiting the region, and an historical sketch of the explorations of the mountains.

These chapters are introductory to the narrative of the explorations by Merzbachen, who, as an Alpine climber, undertook the ascent of the loftiest and most forbidding peaks. The narrative begins with his departure from Munich in 1891, and the details of the journeys are presented with such thoroughness as to constitute a veritable guide-book of the country traversed. Passing through Batum and Kutais to Tschwelieri, the mountains are entered by way of the Lahpari Pass. Following an unsuccessful attempt on Ushba, are the ascents of the Laila and the Tetnuld, the crossing of the Adur-see Pass into the Baksan Valley, the ascent of Elbrus and a series of high peaks east to Kasbek, which, with a journey to Tiflis completes the experience of the first season. The second expedition, in the summer of 1892, was directed to the eastern portion of the range, and a number of lofty peaks ascended, including Tebulos-mta, Komito tawi, and Donos-mta.

The book finishes with a chapter on the map of the mountains and a discussion of the names applied to the peaks and passes; also a petrographical description of rock specimens and fossils collected by the author and studied by Dr. Ludwig von Ammon. Finally, there is a statement of all things possibly needed for such an expedition: clothing, camp outfit and provisions, apparatus, medicines, and presents suitable for those whose favors could not be repaid with money.

J. P. I.

The Geological History of the Rivers of East Yorkshire [England]; being the Sedgwick Prize Essay for the Year 1900. By F. R. Cowper Reed, Trinity College, Cambridge.

In this study the modern physiographic mode of working out the history of topographic and drainage systems is employed with apparent success, following confessedly American precedents. The general conclusions are thought to apply to East England, and perhaps more widely. They are set forth as follows:

By the preceding examination of the geological and physical evidence we have traced the general outlines of the evolution of the present drainage system of East Yorkshire through several successive stages, and we find that its history is intimately bound up with that of the whole of Eastern England since Palæozoic times. There are local details still waiting to be filled in, and branches of the subject still to be investigated, but it is believed that they will produce no evidence which will contradict the main results here worked out. The division of the physical history of the region since Cretaceous times into six stages or cycles is based on geological evidence which is practically incontrovertible; the assumptions as to the original slope of the surface and the deformation of the peneplain are supported by orographical measurements and geotectonic considerations of great weight, as well as by being in harmony with evidence from other parts of England; and, finally, the theory of consequent and subsequent streams has been established on a firm foundation by Davis and many other workers in the same field. The hypothesis of the secondary origin of the Moorland anticlinal as a watershed more or less parallel to the original consequent streams has been found to afford a natural and satisfactory explanation of the behavior and characters of the water courses which it concerns; and the modifications effected by the glacial period have been interpreted in most cases from direct field-evidence.

T. C. C.

The Conveyance of Water in Irrigation Canals, Flumes, and Pipes. By Samuel Fortier. [Bulletin No. 22, Water Supply and Irrigation Papers, Division of Hydrography, United States Geological Survey.]

The paper calls attention to present practices in the conveyance of water in the irrigated districts in different parts of the arid West and points out ways in which works of this character may be built with greater permanence and at less cost than those now in existence. As the relation of the cost of delivering water to the value of the crop to be raised is the vital question in irrigation, this paper should be of especial value to those in anyway affected by the results of irrigation.

The report gives a comprehensive review of the various kinds of irrigation canals and ditches, discussing the faults and merits of each and dwelling on such problems of their operation as the effects of too great or too little grade, the growth of aquatic plants and their removal, the accumulation of ice in winter, and the flow of water as affected by the nature and condition of the conduits.

Considerable attention is given to the construction and serviceability of various kinds of wooden flumes, and their development from the simpler and cruder forms to the expensive but more satisfactory flumes and pipes. There is also a section devoted to the discussion of the cast iron pipes, their history in irrigation, durability and cost.

Copious illustrations and diagrams accompany the report and materially add to its value. As the extent of arid land in the United States is so vast, fully two thirds of its area, and includes some of the richest agricultural land on the globe, this information regarding the methods and growth of irrigation will be welcomed.

G. B. H.

The University Geological Survey of Kansas. Volume IV, Paleontology, Part II. By SAMUEL W. WILLISTON, Paleontologist.

This part two of the paleontology of Kansas is devoted to the description of the Carboniferous invertebrates and the Cretaceous fishes.

The Carboniferous invertebrates, from the Protozoa to Pelecypoda inclusive, have been discussed for the report by Dr. J. W. Beede. All the species have been fully described, so that the report will be a valuable manual for the study of Upper Carboniferous or Coal-measure invertebrates. Not since Meek's report on the Coal-measure faunas of eastern Nebraska, published in 1872 in the final report of the U. S. Geological Survey of Nebraska, has there appeared so comprehensive a report of the faunas of this age, and the report will be of great value to all workers in Upper Carboniferous paleontology whether in Kansas or elsewhere. The paper is illustrated by twenty-two plates. The completion of the report, including the treatment of the additional classes of invertebrates, is promised for the next part of the Paleontology of Kansas to be published by the Survey.

The literature on the Cretaceous fishes of Kansas has been widely scattered in the past, much of it having been published in Germany from collections secured from Kansas for the museums of German univerities, and has been for the most part inaccessible to American students who have not had access to large libraries. In the present report the Selachians and Pycnodonts have been treated by Dr. S. W. Williston, and the Teleosts by Mr. Alban Stewart. These two papers together constitute a comprehensive report of the Kansas Cretaceous

fishes and are a valuable contribution which will be of use not only to the citizens of Kansas, but to all students of fossil fish.

S. W.

Profiles of Rivers in the United States. By HENRY GANNETT. Water-Supply and Irrigation Paper No. 44, United States Geological Survey.

This interesting and valuable publication embodies within a hundred pages the leading facts of about one hundred and fifty of the most important rivers and streams of the country, noting their length, drainage area, the location of water power in their courses, their peculiarities of flow, and the nature of their drainage basins.

The rivers selected are those which are the largest in size and bear most directly upon the varied interests of the country, such as the Connecticut, Hudson, Susquehanna, Ohio, Potomac, Mississippi, Missouri, Platte, Colorado, Sacramento, Columbia, and others. The figures for the tables showing height above sea level and fall per mile were collected from various sources; some were obtained from the report of the chief engineer of the United States army, some from railroad companies when their lines cross streams, and some from the Atlas sheets of the United States Geological Survey.

In the case of such rivers as the Connecticut, Susquehanna, Mississippi, and Colorado, where the surrounding country is, in part or whole, of peculiar physiographic interest, very excellent and vivid descriptions of its leading physical characteristics are given. The pamphlet is the result of much careful work, and is the first attempt to collect and compile this information in its present form.

G. B. H.

Yearbook of the United States Department of Agriculture for 1900. Washington, 1901.

The portions of this important volume of most interest to geologists are those which relate to soil investigation and the special papers on "Mountain Roads," by James W. Abbott: "The Selection of Materials for Macadam Roads," by Logan Waller Page; "Objects and Methods of Investigating Certain Physical Properties of Soils," by Lyman J. Briggs; and "Practical Irrigation," by C. T. Johnston and J. D. Stannard.

C.

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